

Age and Provenance of Long Island Loess

A Thesis Presented

by

Vesna Kundic

to

The Graduate School

In Partial fulfillment of the

Requirements

for the Degree of

Master of Science

in

Earth and Space Sciences

Stony Brook University

May 2005

Stony Brook University

The Graduate School

Vesna Kundic

We, the thesis committee for the above candidate for the

_____ **Master of Science** _____ degree,

hereby recommend acceptance of this thesis.

**Gilbert N. Hanson, Distinguished Service Professor
Department of Earth and Space Sciences**

**Daniel M. Davis, Professor
Department of Earth and Space Sciences**

**Sidney Hemming, Associate Professor,
Department of Earth and Environmental Sciences
Lamont-Doherty Earth Observatory of Columbia University**

This Thesis is accepted by the Graduate School

Dean of the Graduate School

Abstract of the Thesis

Age and Provenance of Long Island Loess

by

Vesna Kundic

Master of Science

in

Earth and Space Sciences

Stony Brook University

2005

According to the Optically Stimulated Luminescence (OSL) ages from the bottom of the loess deposit the deposition of loess in Wildwood State Park kettle hole started at 13,780 \pm 1,100 years ago. The deposition of loess in Stony Brook Campus tunnel valley started at 12,320 \pm 1,290 years ago. The source of dust for Long Island loess was already available around 18,000 years ago in the exposed bed of the drained Lake Connecticut. The late deposition of loess could have been caused by the effect of the anomalous fading or the prolonged presence of stagnant ice and permafrost due to the cold conditions.

Single grain Ar/Ar ages of muscovite and biotite show that the loess provenance is bedrock to the north. Acadian terrane is the dominant component with Avalonian and Taconic terranes as secondary components. The proportion of Taconic to Avalonian signature in the provenance has changed during the loess depositional history.

Wildwood State Park loess deposit is moderately weathered (CIA=66-71) and on the A-CN-K diagram plots close to the average shale. Wildwood State Park loess is depleted in Ca when compared both to the average world loess and to the source region which is explained by Ca mobility. Enrichment in Zr and Hf when compared to Upper Continental Crust (UCC) is a consequence of sorting. Wildwood loess is depleted in Cu and Sr when compared with UCC and in Pb when compared to the source region. The loess is enriched in Light Rare Earth Elements (LREE) and has negative Eu anomaly. Rare Earth Elements (REE) pattern is parallel to the UCC.

Table of Contents

List of Figures.....	vi
List of Tables.....	viii
Acknowledgements.....	ix
Introduction.....	1
I. Geologic Background.....	4
II. Sample Location and Collection.....	7
III. Analytical Techniques.....	14
Ar/Ar Dating.....	14
OSL Dating.....	15
Grain Size Analysis.....	16
Major and Trace Elements Analysis.....	17
IV. Age of Loess on Long Island.....	21
V. Provenance of Loess on Long Island.....	32
VI. Major, Trace and REE Elements.....	40
VII. Conclusion.....	52
References.....	54

List of Figures

1.	Bedrock map of Connecticut (Zhong, 2002).....	5
2a.	Biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).....	6
2b.	Muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).....	6
3.	Topographic low as a sediment trap.....	7
4.	Topographic map of the kettle hole in Wildwood State Park.....	9
5.	GPR profile from Wildwood State Park kettle from 0 to 120m.....	10
6.	Auger samples diagram.....	11
7.	Topographically uncorrected GPR diagram from Wildwood State Park kettle...	12
8.	Resistivity diagram from Wildwood State Park kettle.....	12
9.	Grain size distribution in loess from Wildwood State Park.....	23
10.	Glacial history of Long Island and the area to the north.....	25
11.	Illustration of the vibra core from Wildwood State Park with ages.....	31
12.	Wildwood State Park muscovite Ar/Ar ages.....	33
13.	Wildwood State Park biotite Ar/Ar ages.....	34
14.	Biotite and muscovite Ar/Ar ages from Stony Brook Campus (Zhong, 2000.)...	35
15.	Biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).....	36
16.	Muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).....	36
17.	Ar/Ar ages of muscovite organized into source regions.....	37
18.	Map of Long Island Sound drainage basin with watersheds.....	39
19.	A-CN-K diagram of Wildwood State Park loess.....	41

20.	Major elements from 58 samples around the world (Pye, 1999).....	43
21.	Major elements from Wildwood State park normalized to NURE.....	44
22.	Ti/Al ratio of Wildwood loess and New England stream sediment.....	46
23.	Trace elements from Wildwood state park plotted against UCC.....	47
24.	Wildwood State Park trace elements normalized to UCC.....	48
25.	Wildwood State Park loess trace elements normalized to trace elements from stream sediments in New England.....	50
26.	Chondrite-normalized REE diagram.....	51

List of Tables

1.	List of results of major, trace and REE elements analyses.....	20
2.	Normalized Wildwood State Park loess major elements.....	46

Acknowledgements

I would like to thank my advisor Gilbert Hanson. He helped me with advice and guidance and I can freely say that this thesis would not exist if he was not here. He introduced the world of science to me and I will be grateful for that for the rest of my life. His wisdom and enthusiasm kept me going. I can not think of any word big enough that could express my gratitude. Thank you.

I would like to thank the members of the committee, Sidney Hemming and Dan Davis. They were both my advisors and I could not ask for better. Thank you for all your help, advice and patience.

Isotope lab crew is probably the coolest crowd in the building. You guys are great colleagues and friends and a lot of fun. I am very happy and grateful that I have met you all.

Mom and dad gave me life and the opportunity to do anything I wanted. They have supported me and guided me to the best of their knowledge and I am thankful from the bottom of my heart. My brother Zeljko is my best friend in the world. He was always there for me, trying to help me and comfort me. Thanks, Zac.

Finally, I would like to thank my husband Tomislav. His love and support are the essential part of my life and I know that I can always rely on him. Thank you “Pajcek”.

INTRODUCTION

Loess is unconsolidated, wind deposited sediment composed mainly of silt-sized particles. Loess deposits are homogeneous and show little or no stratification. Its formation requires a large source of dust, wind for transport and a sediment trap for deposition (Pye, 1995). As a result, almost all loess deposits were accumulated during glacial periods when the atmosphere was windier and ice sheets were producing large quantities of silt. For that reason, these deposits are considered one of the best paleoclimate records on land (Pye and Sherwin, 1999). Loess deposits are able to capture small scale local changes (Kukla and Cilek, 1996) as well as large scale changes that correspond well to the deep sea records and can be used to test the global climate models (Pye, 1995). Additionally, dust in the atmosphere is not just a consequence of climate but can also affect the climate by cooling or heating the atmosphere (Arimoto, 2001). The long-term record of climate change is well known from the many cores in marine sediments where there is continuous sediment deposition. However, small glaciers oscillations or other small scale local changes cannot affect the oxygen isotope record but can be preserved in proximal loess deposits. In order to interpret the loess record and use it to decipher climate conditions and wind patterns in the past, the knowledge about its source and type of transport is very important (Mason et al., 1999). Knowing the time of the deposition of windblown silt puts a time constraint to processes related to formation

of the loess deposit and availability of the sediment sources. Time of deposition provides knowledge about the deposition rates and makes it possible to correlate loess record with other paleoclimate records (Porter, 2001, Maher et al., 2003, Roberts et al., 2001). Loess was studied for different reasons and in different regions of the world. In Asia, where the thickest loess deposits in the world can be found, loess is studied to reconstruct paleoclimate and East Asian monsoon climate in the past (Porter, 2001, Maher and Thompson, 1995, Rousseau and Kukla, 2000, Bronger et al., 1998) and for provenance (Jahn et al., 2001). In the US only after 1930 loess was considered an eolian deposit. Before that it was thought to be a fluvial deposit (Follmer, 1996). Since then it was studied in multiple locations across the US but mostly in the Midwest where the deposits are the thickest. Petrography and stratigraphy of loess (Swineford and Frye, 1950, Frye and Leonard, 1951) and paleowinds were studied in Kansas (Arbogast and Muhs, 2000) and in Iowa (Muhs and Bettis, 2000), loess distribution and composition was studied in southeastern Illinois and southwestern Indiana (Fehrenbacher et al., 1965b, Fehrenbacher et al., 1965a) The thickness of Peoria and Roxana loess deposits was studied in Illinois (Fehrenbacher et al., 1986). Multiple loess units were identified in modern soils in Nebraska (Kuzila, 1995, Mason and Kuzila, 2000) and loess deposits in Colorado and Nebraska were used to study the climate change (Aleinikoff et al., 1999; Muhs et al., 1999a; Muhs et al., 1999b). Loess was also identified in Pennsylvania (Carey et al., 1976) and recognized in soils in Delaware, Maryland and northeastern Virginia (Simonson,

1982, Foss et al., 1978) and lately is also studied in Alaska (Muhs et al., 2003, McDowell and Edwards, 2001).

Unfortunately, there was very little work done on Long Island loess. Apart from Jian Zhong provenance study and some work by Les Sirkin and William Nieter (Nieter and Krinsley, 1976; Nieter et al., 1975) silt deposit was not even recognized as loess.

On Long Island, loess deposits range from a few centimeters to several meters in thickness. In order to establish the provenance of loess from Wildwood State Park we have used $^{40}\text{Ar}/^{39}\text{Ar}$ ages of single biotite and muscovite grains. This technique enables us to quantify the potential sources and to eliminate the problem of averaging the source as would be the case if we used bulk samples.

Time of the deposition was determined using Optically Stimulated Luminescence (OSL) and ^{14}C on charcoal grains that were found in the deposit. Timing of loess formation is very important because it can be compared with other processes in the area that influenced the loess deposition at the time, like the possibility of permafrost presence and drainage of proglacial lakes to the north.

Major, trace and REE elements were used to put as many constraints as possible to the environment in which Long Island loess was deposited and the source rocks from which it was produced.

I. GEOLOGIC BACKGROUND

The area to the north of Long Island formed through a series of collisions and rifts and four orogenies gave the shape to it. Grenville orogeny was a result of a collision of North America with a continent to the southeast at 1100-1200 million years (Ma) (Zartman and Hermes, 1987). This collision created a Proterozoic Supercontinent called Laurentia (Rankin, 1994, Condie, 2002). As early as 723 Ma the continent started braking up (Kamo et al., 1995) and Iapetus Ocean formed (Rankin, 1994). Grenville orogeny terrain was split as the ocean was created but fragments of it were left on the Laurentian side of the continental margin (Rankin, 1994). Taconic orogeny was an outcome of the Laurentian continent margin collision with the island arc bordering the existing terranes at 470-440 Ma and it is an indicator of the Iapetus Ocean closure (Rankin, 1994 315). Acadian orogeny metamorphism occurred at 410-380 Ma but the plate motions responsible for it are in disagreement (Rankin, 1994). In the period between Taconian and Acadian orogeny a large amount of sediment from Taconian highlands was deposited in the foreland basin and became a part of Acadian terrain (Rankin, 1994 315). The last orogeny in eastern North America, Alleghenian, occurred around 330-250 Ma when North America and West Africa collided and formed a supercontinent Pangaea (Rankin, 1994). When the Pangaea started braking and present Atlantic Ocean started forming, a portion of North Africa-Amaozonia known as Avalon stayed attached to North American

continent (Dorais and Paige, 2000, Obrien et al., 1983). Rocks of Avalon terrane are exposed in large areas of southeastern Connecticut. Avalon is tectonically important because it is thought that its collision with Laurentia has caused either Acadian or Alleghenian orogeny (Dorais et al., 2001). The significance of this terrain for this study is its distinctive $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages of mica (Dorais et al., 2001) which are approximately between 310 and 220 Ma (Wintsch et al., 2001).

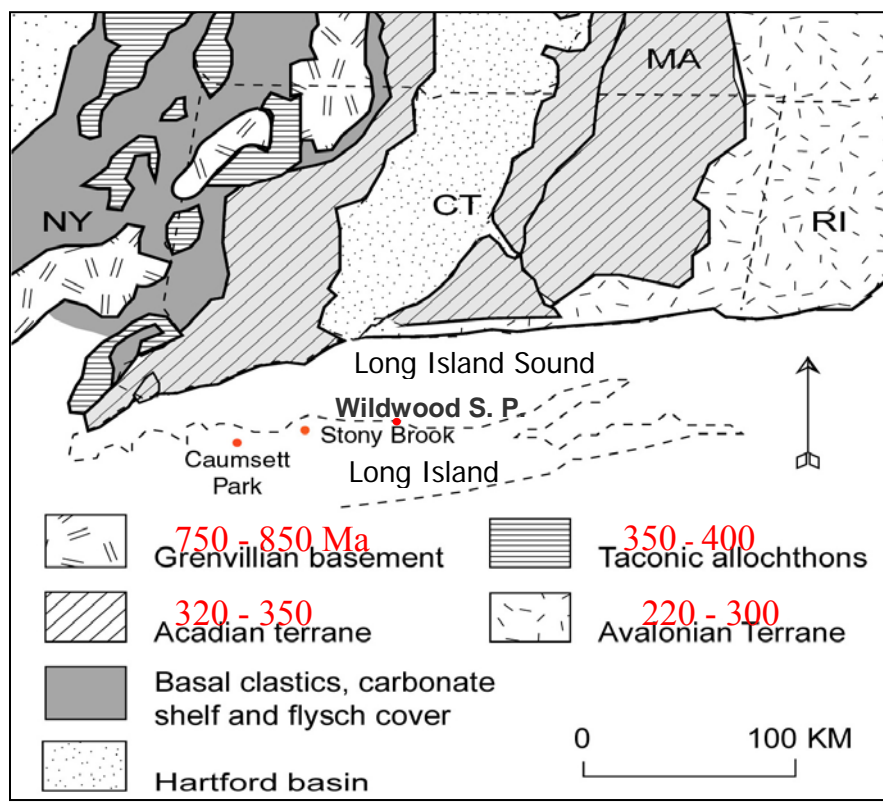


Figure 1. Bedrock map of Connecticut (Zhong, 2000). Shown in red are the Ar/Ar cooling ages of mica in the Connecticut bedrock.

In this study, we are using closure temperatures and $^{40}\text{Ar}/^{39}\text{Ar}$ cooling ages of mica for provenance. Ages of mica in the bedrock north of Long Island have range between 200 and 900 Ma (Zartman, 1995). $^{40}\text{Ar}/^{39}\text{Ar}$ ages east of the Hartford Basin are between 200-300 Ma, western Connecticut ages are between 300-400 Ma and in the northwestern part of Connecticut and eastern New York the ages go above 400 Ma (Zartman, 1995) (Figure 2a and 2b).

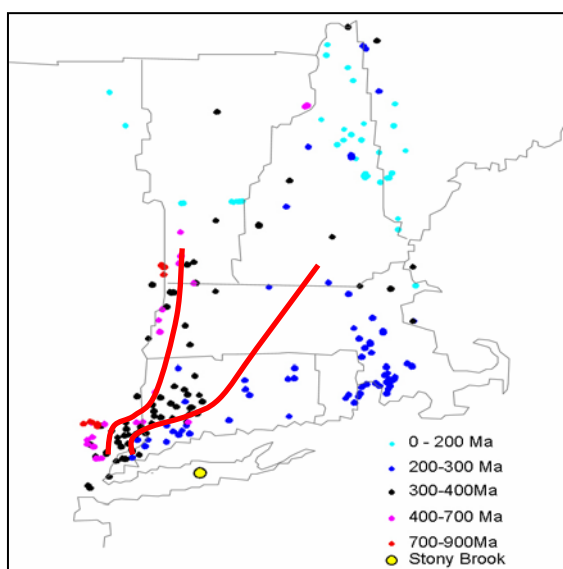


Figure 2a. Biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).

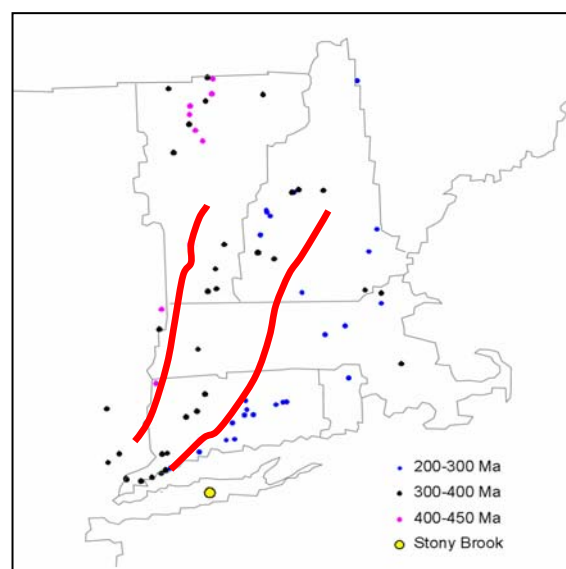


Figure 2b. Muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).

II. SAMPLE LOCATION AND COLLECTION

Loess is ubiquitous on Long Island but mostly it is only a few inches thick. To avoid the effects of weathering and bioturbation or any post depositional disturbances we looked for sites with at least 1 m of loess. When collecting samples for OSL dating one also has to take into account that the paleodose sample should have been covered by at least 0.3 m of overburden at the time it was buried and the sediment should not be exposed to light since deposition (Aitken, 1998). Suffolk County soil survey distinguishes a type of soil called silt loam, which develops wherever there is loess at the surface (1975; US Department of Agriculture, 1975). In order to find a thick loess section, one has to look for places that would catch and collect windblown sediment better than areas that surround it. Topographic lows are very efficient sediment traps (Pye, 1987) and windblown sediment is preferentially deposited in topographic features such as kettle holes and valleys.

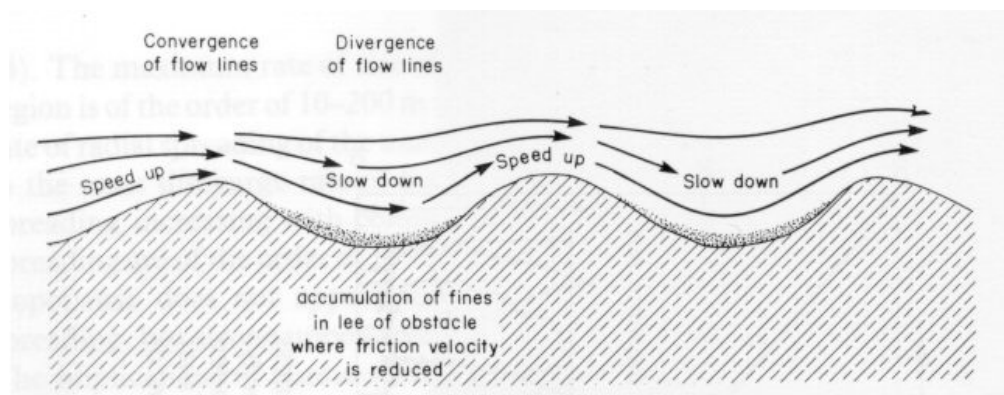


Figure 3. Topographic low as a sediment trap. When passing over a topographic low wind loses its speed. Its ability to carry sediment is reduced and fine silt particles are being deposited in such lowlands creating a lens of loess at the bottom. (Pye, 1987)

Loess samples were collected from a shallow tunnel valley on Stony Brook Campus and from a kettle hole in Wildwood State Park. The Stony Brook Campus loess deposit is about 1 meter thick and was previously studied for grain size analysis and provenance (Zhong, 2000). Loess from this location was sampled for OSL dating by hammering a 30 cm long and 8 cm wide aluminum pipe into the section wall close to the bottom of the deposit.

Wildwood State Park kettle is 65 m wide, 230 m long and 10 m deep and contains almost 3 m thick loess layer at its bottom. The kettle hole is on the Harbor Hill moraine 20 km east of Stony Brook and about 1 km south from Long Island Sound shore and it is elongated in the E-W direction.

To determine the extent of loess at the bottom we used Ground Penetrating Radar (GPR), resistivity and augering.

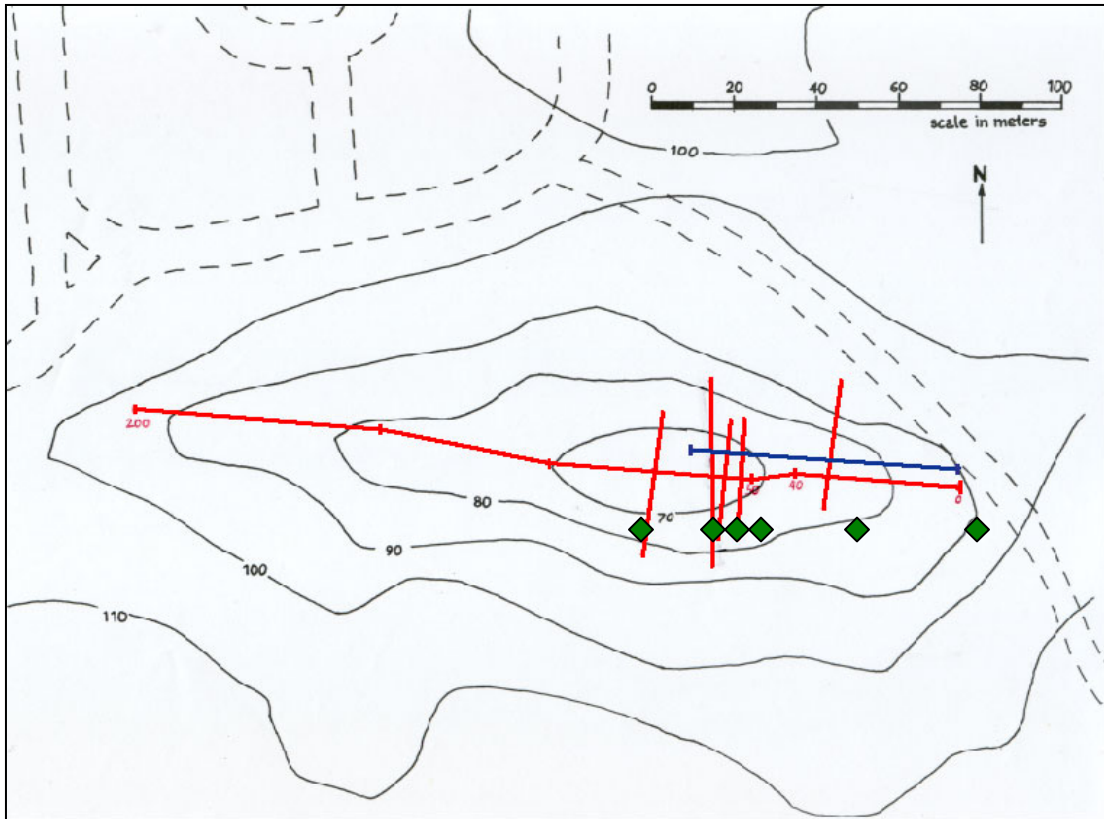


Figure 4. Topographic map of the kettle hole in Wildwood State Park. GPR lines are shown in red, resistivity line in blue and auger sampling sites as green diamonds.

GPR device sends impulses of radio waves into the ground and those waves are reflected from subsurface contacts. Output is represented as a profile in which layers can be seen as bands of different shades of gray. GPR profiles at the bottom of the kettle show a lens of loess underlain by till which was confirmed by augering along the GPR line. Seven auger samples were taken along the GPR line with the first at 18 m from the east edge of the kettle and the last one at 104 m. Loess was covered with a thin layer of sand and gravel on the kettle slopes and at the bottom loess was at the surface. Loess was

thickest in the 64 m auger hole where it was 270 cm thick. A resistivity line was also measured along the GPR line. Resistivity distinguishes sediments in regard to their electrical properties. The resistivity profile from Wildwood State Park shows less resistant material sitting on top of a more resistant material. Based on the GPR and auger sampling this less resistant material is interpreted as loess overlying till.

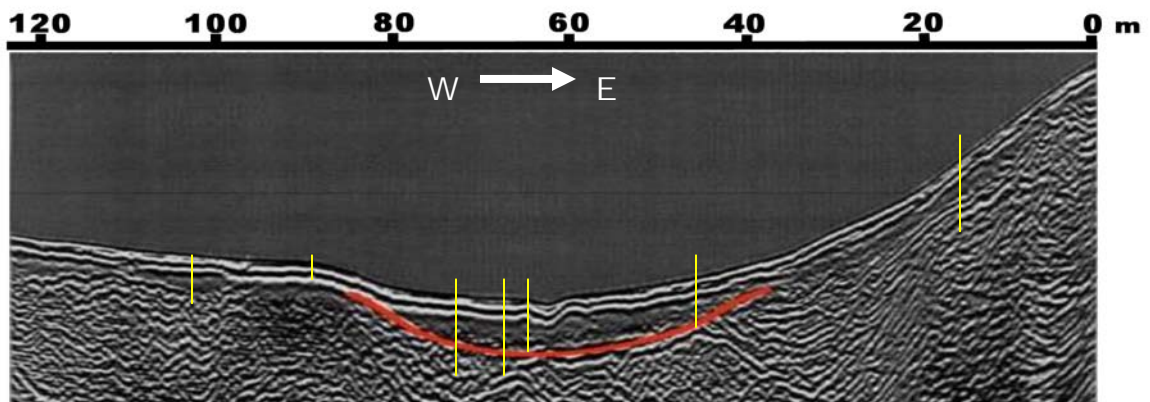


Figure 5. GPR profile from Wildwood State Park kettle from 0 to 120m. Outlined in red is loess deposit. The sharp reflecting surface below the loess is till. This is confirmed by auger sampling shown in yellow. This diagram was corrected for topography and as a result, the scale above is only approximate. Length of the yellow lines does not represent the actual depth of augering.

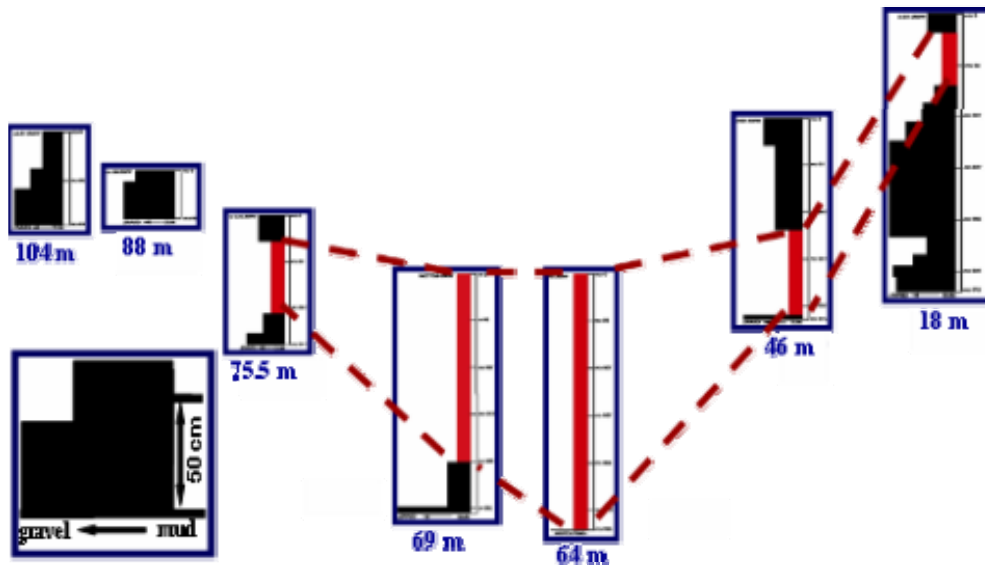


Figure 6. Auger samples diagram. Seven auger samples were made along the GPR line with the first at 18 m from the east edge of the hole and the last one at 104 m. At 18 m auger hole we found 50 cm of loess covered by 20 cm of sand and gravel and underlain by gravel. At 46 m under 120 cm of sand and gravel we collected 145 cm of loess which was underlain by sand and gravel. At 64 m loess was found at the surface and it is 270 cm thick. At 270 cm the auger hit an obstruction, most likely till. At 69 m loess was still at the surface but 200 cm thick and underlain by 50 cm of sand and gravel and then till. At 75.5 m the loess 80 cm thick is covered with 25cm of sand and underlain by till. No loess was found at 88 m or 104 m away from the east edge of the kettle. At 104 m there was 40 cm of sand at the top overlying sand mixed with gravel.

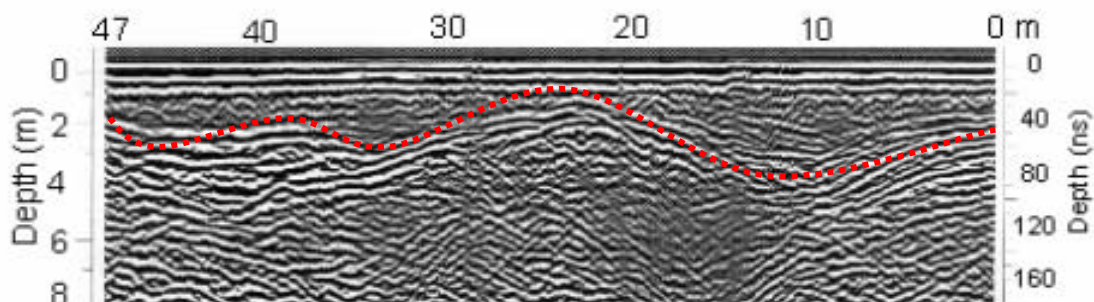


Figure 7. Topographically uncorrected GPR diagram from Wildwood State Park kettle. The boundary between loess and till is outlined in red dotted line.

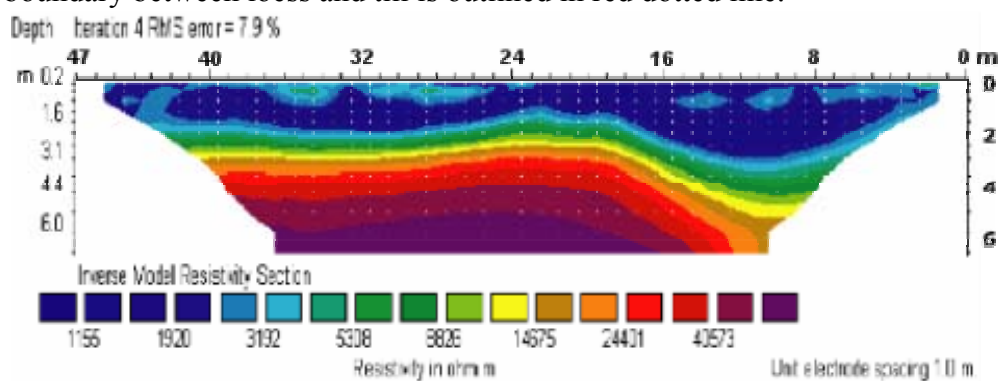


Figure 8. Resistivity diagram from Wildwood State Park kettle. The diagram shows loess in blues and greens and underlying till in reds and it follows the GPR (above) diagram closely.

Two Vibracore samples were collected. The first was sampled in the summer of 2002 at which time the loess was very dry and difficult to core. The core was taken in three increments with a total length of 270 cm. Portions of this core were used for the OSL dating. After the core was split samples were taken for Ar/Ar dating and some charcoal grains were collected for ^{14}C dating. The core was sampled every 10 cm. The second

sampling by Vibracore was performed in the fall of 2002. The loess was moist so it was easier to Vibracore and a continuous core was obtained. The depth of the core was 255 cm but contained only 190 cm of loess due to compression. The second core was used for grain size and major and trace elements analyses. Samples were taken at 10 cm increments starting below the soil line at 90 cm. Both cores were described in detail and color was determined using the MUNSEL Soil Color Charts. Cores were dark olive brown (2.5Y3/3) at the very top and dark yellowish brown (10YR3/4-6) to strong brown (8.75YR3/5) and dark brown (7.5R3/3.5) within the first 1 meter. Second core was yellowish to dark yellowish brown (10YR4/4-3) from 110 cm to the 190 cm (bottom). First core was in the same yellowish to dark yellowish brown color (10YR4.5/6) in the middle but was darker in the lowermost part where it was very dark grayish brown to dark brown and dark yellowish brown (10YR2.5/2 to 10YR3.5/4).

III. ANALYTICAL TECHNIQUES

Ar/Ar Dating

Biotite and muscovite grains for Ar/Ar dating were handpicked from seven loess samples from Wildwood State Park. Bulk loess samples were dried under heat lamps and then dry sieved. The fraction, finer than 125 μm , was then mixed with water and a dispersing agent (Calgon 2.5 g/l). It was placed in an ultrasonic bath for 20 minutes and then wet sieved using 70 μm sieve. Greater than 70 μm fraction was rinsed with a mixture of the dispersing agent and water and then with deionized water and finally ethanol. With this procedure the finest particles were removed and what is left is a clean sample of silt and fine sand. This clean sample was covered with ethanol and mica grains were handpicked with forceps under a microscope. Biotite and muscovite samples were wrapped in aluminum foil, placed into twelve-hole aluminum discs and sent to the reactor for irradiation.

Laser fusion single grain $^{40}\text{Ar}/^{39}\text{Ar}$ analyses were performed at the Lamont-Doherty Ar Geochronology Laboratory that consists of a fully custom built and automated micro-extraction system and a VG5400 mass spectrometer. Grains were fused with CO_2 laser and gases released during the heating of the samples are scrubbed of reactive gases such as H_2 , CO_2 , CO , and N_2 by exposure to Zr-Fe-V and Zr-Al sintered metal alloy getters.

The remaining inert gases, principally Ar, are then admitted to the mass spectrometer. Ar isotopic ratios are determined using automated data collection software (Al Deino, Berkeley Geochronology Center). The mass spectrometer was operated in static mode.

J value was calculated from analyses of co-irradiated Mmhb hornblende, assuming an age of 520.5 Ma. (Samson and Alexander, 1987). Ages for the samples were calculated from Ar isotope ratios corrected for mass discrimination, interfering nuclear reactions, procedural blanks, and atmospheric Ar contamination. Further refinement of sample's ages was made by examining the combination of the ^{39}Ar content and the radiogenic content after Ar isotopes analysis. Ages for samples with low ^{39}Ar (potassium) content or less than 10% radiogenic ^{40}Ar were discarded due to the large uncertainties in the ages.

OSL Dating

Samples for OSL dating were collected from Wildwood State Park and from Stony Brook Campus loess deposits. The Wildwood State Park loess samples were collected on two occasions by vibra-core which produces a core sample that is encased in aluminum pipe. Samples for OSL dating were taken from a core which reached 270 cm in depth. Approximately 20 cm long cut offs were sealed on each end of the core to be dated in order to prevent the light from reaching the sediment. Three such core segments were collected for dating. The bottom segment came from 270-262cm depth, the middle one

from 208-200 cm, the upper one from 129-121 cm. We did not take a sample from higher in the core to avoid loess affected by soil processes. Optically stimulated luminescence (OSL) measures the time that has passed since the sediment was last exposed to light. It is important to avoid samples that might have been bioturbated or exposed to light in any other way since the initial deposition. The Stony Brook Campus loess sample was taken by driving 30 cm long aluminum pipe into the face of the section near the bottom of the one meter thick section. The pipe ends were covered with duct tape and plastic covers. The OSL ages were determined in the Luminescence Dating Research Laboratory at the University of Illinois in Chicago. Fine grain (4-11 μm) polymineral fractions of sediments were dated by Infrared Stimulated Luminescence (IRSL) under 880 ± 80 nm stimulation.

Grain Size Analysis

Grain size analysis was performed on 5 samples from one of the cores at Wildwood State Park loess deposit. Coring reached 255 cm of depth but the core contained only 190 cm of sediment due to the compaction. The core was split and samples were taken at 20 cm intervals starting below the soil line. Grain size analysis was performed in Marine Sciences Research Center at Stony Brook University. Individual samples were weighed carefully and approximately 20 grams were used for analyses. The sample was sieved

with the 2mm mesh sieve to remove the coarsest particles. This fraction is then weighed and recorded. The coarse organic matter (roots etc.) was hand picked and the rest of the sample was put into a 500 ml glass beaker. The sediment was covered with deionized water and placed on a hot plate at very low heat. To destroy the remaining organic material, every 10 min 5 ml of H_2O_2 was added and the mixture was stirred occasionally. This procedure was repeated until the fizzing resulting from the reaction of H_2O_2 with organic matter stopped. Then, 10 ml of dispersing agent (Calgon) was added and the beaker was placed into the ultrasonic bath for 10 min. The deflocculated and dispersed sample was wet sieved using 63 μm mesh. Fraction coarser than 63 μm was dried in the oven at 60°C over night and then dry-sieved using Sonic Sifter. The meshes used were no. 14, 18, 25, 35, 45, 60, 80, 120, and 17 giving size fractions in $1/2\Phi$ increments. The finer than 63 μm fraction was analyzed using SediGraph 5000ET grain size analyzer. Both measurements (SediGraph and Sonic Sifter) were combined using Excel spreadsheet.

Major and Trace Elements Analyses

Samples for major and trace elements analyses were collected from the second vibracore at 112 cm, 152 cm and 192 cm below the top of the core. Those three loess samples were dried under a heat lamp. Approximately 10 g of each dried sample was ground in an

agate Spex 8500 Shatterbox for 1 minute. Major and trace elements analyses were performed at Washington State University Geoanalytical Laboratory. Their laboratory consists of Hewlett-Packard ICP-MS and Rigaku automated X-ray fluorescence spectrometer (XRF). ICP-MS consists of a quadrupole mass spectrometer with inductively coupled argon plasma as an ion source. The elements analyzed, besides the major elements, include all 14 naturally occurring rare earth elements (La through Lu) plus Ni, Cr, V, Ba, Rb, Y, Nb, Ga, Cu, Zn, Cs, Hf, Ta, Pb, Th, U, Sr, Zr and Sc. The concentrations of major and trace (Ni, Cr, Sc, V, Ba, Rb, Sr, Zr, Y, Nb, Ga, Cu, Zn, Pb, La, Ce and Th) elements are measured on Rigaku 3370 XRF Spectrometer with a rhodium (Rh) target run at 50 kV/50 mA with full vacuum and a 25 mm mask for all elements and all samples. Samples were prepared with a low (2:1) Li-tetraborate fused bead technique (Johnson, 1999). Under such sample preparation and spectrometer running conditions the uncertainty for major elements measurements may be regarded as insignificant for most geological correlations (Johnson, 1999). Major elements concentrations are normalized to a 100% on a volatile-free basis. Total Fe is expressed as FeO.

In XRF measurements, among the trace elements the precision, and therefore the accuracy, of Ni, Cr, Sc, V, and Ba is less than for Rb, Sr, Zr, Nb, Y, Ga, Cu, and Zn which correlates in part with the lower count rates (cts/sec/ppm) for Sc, V, and Ba using a Rh target. Ni, Cr, Sc, V, and Ba are regarded as only semi quantitative below the 30 ppm level which is applicable to Ni and Sc from Wildwood State Park loess. Rb, Sr, Zr, Nb,

Y, Pb, and Th have satisfactory precision and accuracy down to 1 to 3 ppm. La and Ce concentrations are qualitative only. Since XRF technique loses precision at low trace elements concentrations at these lower concentrations, below 10 ppm and for some elements, below 30 ppm, ICP-MS measurements are preferable. XRF procedure is described in more detail in (Johnson, 1999).

The concentrations of 14 naturally occurring rare earth elements (La through Lu) and 13 trace elements (Ba, Rb, Y, Nb, Cs, Hf, Ta, Pb, Th, U, Sr, Zr and Sc) were measured by ICP-MS

XRF					ICP-MS				
Normalized Major Elements (Weight %):				uncertainty	REE and trace elements in ppm				uncertainty
	108-112	148-152	188-192	% std dev		108-112	148-152	188-192	% std dev
SiO ₂	78.265	78.748	80.034	0.132	La	44.961	45.529	40.828	2.265
Al ₂ O ₃	11.590	11.519	10.795	0.457	Ce	87.040	93.175	86.393	1.424
TiO ₂	0.919	0.905	0.828	0.601	Pr	9.784	9.867	8.967	1.910
FeO*	3.878	3.823	3.269	0.260	Nd	37.670	38.075	34.448	1.482
MnO	0.152	0.091	0.056	2.703	Sm	7.931	8.131	7.523	1.957
CaO	0.586	0.564	0.721	0.498	Eu	1.393	1.409	1.254	2.074
MgO	1.028	0.974	0.904	9.174	Gd	6.605	6.716	6.314	1.496
K ₂ O	1.901	1.865	1.879	1.261	Tb	1.085	1.084	1.012	1.815
Na ₂ O	1.397	1.373	1.452	1.724	Dy	6.773	6.569	6.039	1.399
P ₂ O ₅	0.285	0.138	0.063	0.699	Ho	1.385	1.336	1.213	1.352
Unnormalized Trace Elements (ppm):					Er	3.949	3.766	3.381	1.591
Ni	17	21	17	6.250	Tm	0.584	0.555	0.511	1.755
Cr	44	43	41	12.500	Yb	3.766	3.557	3.307	1.159
Sc	11	4	17	50.000	Lu	0.598	0.562	0.526	2.062
V	81	78	66	9.259	Hf	15.210	14.152	11.882	2.359
Cu	8	8	6	6.452	Ta	1.369	1.374	1.379	9.011
Zn	54	51	43	1.942	U	3.358	3.314	3.140	9.115
Ga	14	12	12	4.348	Cs	2.907	2.684	2.291	12.249
La	51	53	50	5.435	Sc	11.970	11.821	11.515	3.465
Ce	92	114	104	2.506					
Elements analyzed with both techniques					Elements analyzed with both techniques				
Ba	375	384	370	0.696	Ba	375.491	390.139	372.822	2.462
Th	17	16	15	1.887	Th	15.417	15.142	15.205	7.293
Nb	17.4	16.9	17.2	1.825	Nb	17.728	17.264	16.698	4.713
Y	36	36	33	3.333	Y	37.003	35.507	31.694	1.719
Pb	16	16	14	3.774	Pb	17.616	17.705	16.845	10.161
Rb	77	70	69	0.395	Rb	71.255	64.631	63.393	6.702
Sr	89	91	102	0.429	Sr	89.178	89.824	98.094	1.555
Zr	569	536	466	0.190	Zr	555.085	517.785	430.716	

Table 1. List of results of major, trace and REE elements analyses by analytical techniques and standard deviations expressed as percentage. Standard deviation was calculated from the 50 measurements of single sample TED measured over four year period 1995-1999 on ICP-MS and also from measurements of a single bead of GSP-1 sample measured over 8 month period on XRF (Johnson, 1999) at WSU Geoanalytical laboratory. Standard deviation was then expressed as a percentage of the average of results for each element.

IV. AGE OF LOESS ON LONG ISLAND

Throughout the process of collecting samples for OSL dating, one has to be careful not to expose the sample of interest to the light. The dating was performed in Luminescence Dating Research Laboratory at University of Illinois at Chicago. Three portions of the vibra core sample were taken from Wildwood State Park for OSL dating; one from just below the soil line, one from the middle of the core and one from the bottom. All segments were carefully closed on ends to prevent the light exposure. The OSL ages from Wildwood State Park were $13,780 \pm 1,100$ years for the bottom of the deposit, $13,400 \pm 1,250$ years for the middle and $7,730 \pm 690$ years for just below the soil line. The age at the bottom of the deposit implies that the deposition in the kettle has started around 13,000-14,000 years ago.

Unlike these OSL loess ages, most of the glacial history of the area is reported in radiocarbon years which need to be handled carefully because they can be significantly different from calendar years (Hughen K., 2004). All ^{14}C ages from the literature needed to be converted in order to be comparable. This was done with CALIB Radiocarbon Calibration program (Stuiver et al., 2005). After calibration we have compiled Long Island glacial history using the New England deglaciation chronology that was composed using atmospheric ^{14}C calibrated varve chronology (Ridge et al., 1999; Ridge and Toll, 1999).

When the ice sheet started retreating, a proglacial lake called Lake Connecticut was formed between the Harbor Hill moraine on the south and Connecticut coast on the north. Loess deposition on Long Island could have started as soon as the lake drained and its bottom was exposed around 18,800 years ago (Lewis and Stone, 1991). Melt water streams that were coming of the ice sheet were bringing glacial silt and depositing it in the broad valley of the Lake Connecticut's exposed bed. This freshly deposited silt could have been the first local dust source for Long Island loess. Grain size analyses from Wildwood State Park loess show a peak in sand sized grains as well as silt. This suggests that the source of dust was not very far away and the deposit is only 1 km south of the Long Island Sound.

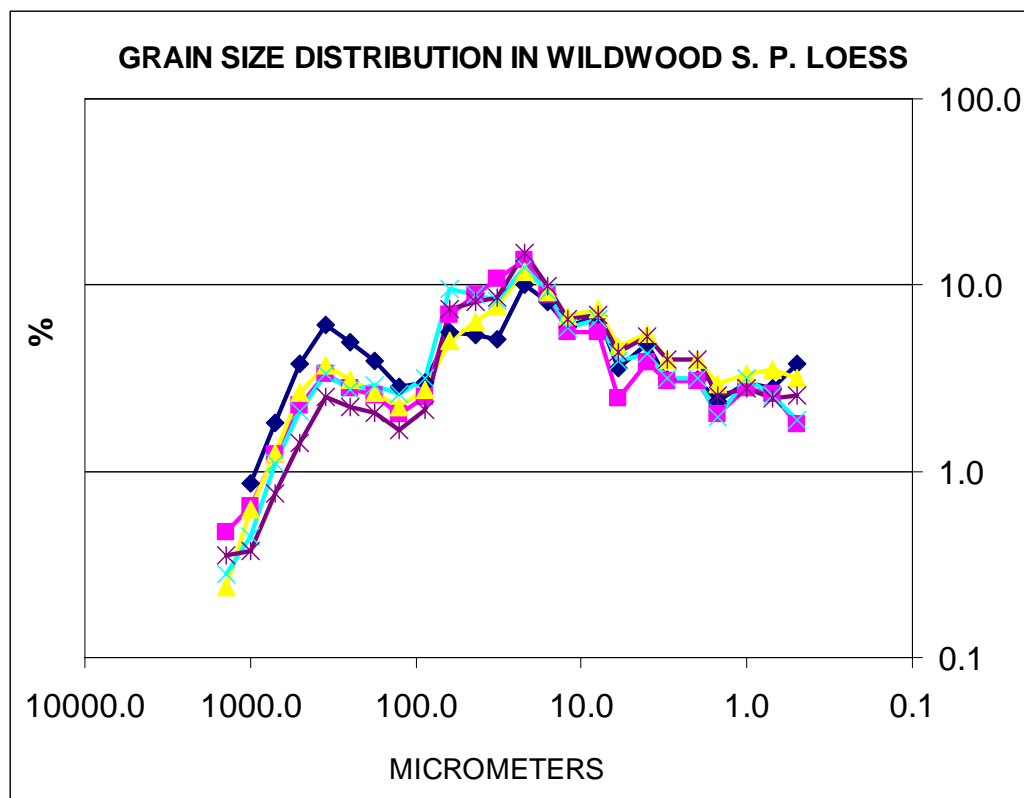


Figure 9. Grain size distribution in loess from Wildwood State Park. Loess shows two peaks, sand and silt. The presence of sand peak indicates the proximity of the source because the sand grains can travel with the wind to short distances and get deposited in the same sediment traps as silt sized sediment.

Loess deposition would have to stop or be significantly decreased when the Sound was covered with water again. By 14,500 calendar years ago a relative sea level in Long Island Sound was -40m (Lewis and Stone, 1991). At this level, the sea would cover the eastern part of Long Island Sound Basin reducing the source areas to fresh delta deposits in the northern and northwestern areas of the Sound Basin. Another possible source was fresh stream deposits in the drained bed of Proglacial Lake Hitchcock. Lake Hitchcock

drained between 16,400 and 15,300 calendar years ago (Stone, 1992). Ridge (Ridge et al., 1999) suggested that the lake occupied the upper Connecticut Valley only for a short period of time and also that macrofossils that gave such ages came from reworked older sediment so the lake might have drained even earlier. According to our OSL ages, the deposition of loess at Wildwood State Park started about four thousand years after the Lake Connecticut drained. This delay might have been caused by cold climate and presence of permafrost. If permafrost conditions in the area prevailed until about 14,000 calendar years ago, buried ice inside the Wildwood kettle would probably still be present until that time and the depression would not be created. The presence of permafrost is indicated by the existence of pingo scars and ice wedges in the drained bed of Lake Hitchcock several thousand years after the ice has left (Stone, 1992). However, there are no reports that indicate the presence of permafrost features on Long Island.

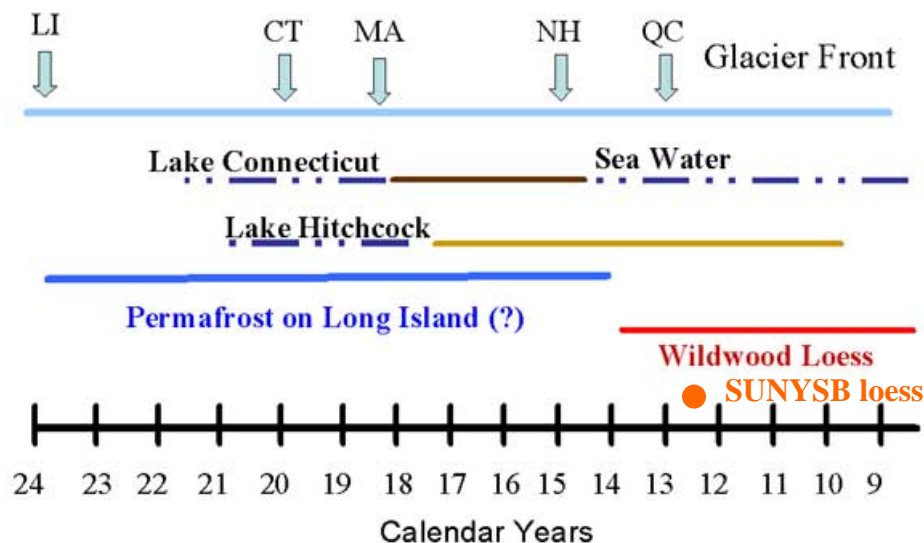


Figure 10. Glacial history of Long Island and the area to the north. Horizontal lines represent approximate time span of events. Radiocarbon ages have been converted to calendar ages (Stuiver, et al, 1998). Approximate position of the front of the continental glacier in calendar years after retreating from Long Island (LI) (Stone, 1986) when it reached Connecticut (CT) (Stone, 1986), Massachusetts (MA) (Uchupi et al., 2001), New Hampshire (NH) (Ridge et al., 1999) and Quebec (QC) (Ridge et al., 1999) and reference therein, (Miller and Thompson, 1979). Light and dark brown lines represent time after Glacial Lake Hitchcock (Stone, 1992) and Glacial Lake Connecticut completely drained (Lewis and Stone, 1991) and their lake beds were dry with glacial melt water streams crossing them. Broken blue line represents the time when fresh or sea water was occupying the lake basins. The dark blue line is the time when Long Island may have had permafrost. The Red line shows period of deposition of loess in Wildwood State Park kettle hole as measured with OSL and radiocarbon ages. Orange dot shows the OSL age at the bottom of the loess deposit at Stony Brook Campus.

To approach this problem we needed to find a loess deposit that is formed in a shallow and small sediment trap, one that would be available immediately after the ice sheet retreat. Loess deposit on Stony Brook Campus is located on the north shore of Long

Island 20 miles west of the Wildwood State Park. The deposit is about 1 m thick and it is formed at the bottom of a shallow tunnel valley. We assumed that the deposition of loess in the tunnel valley could have started soon after the ice sheet retreated. Around 20,500 years ago the ice sheet was at the Connecticut shoreline (Stone and Borns, 1986) and the first source of silt was available at 18,800 calendar years ago (Lewis and Stone, 1991). We do not expect that the valley contained any ice. If there was ice in the tunnel valley, it could not have been thick since the valley is only a couple of meters deep and the ice would melt rapidly. Therefore, this valley was a sediment trap which should have been available for loess deposition at 18,800 years ago.

The OSL age close to the bottom of the deposit in Stony Brook was $12,320 \pm 1,290$ years and this means that the loess deposition in this valley started close to the time of the Wildwood State Park deposition. In actuality, the OSL age means that the loess at the bottom of the deposit was exposed to the light at that time by some process. OSL ages can be reset in a very short time especially in silt size grains. After 10 seconds of exposure to sunlight, natural unbleached optical signal of quartz is reduced to 1% of its value and for the feldspar this happens in 9 minutes (Godfrey-Smith et al., 1988). Therefore, it takes very little sun exposure to reset the OSL age and this could be easily accomplished by colluviation or some kind of soil mixing. Grain size analysis was studied at the same site (Zhong, 2000) and pebbles 2-4 cm in diameter were reported to be mixed in with the loess. Small rock rounded fragments or gravel layers can be indicative of continued colluvial activity and retransported silt (Ferraro, 2004; McDowell

and Edwards, 2001). Furthermore, only 0.5% of inclination is an assumed threshold value of slope steepness for erosion (Frielinghaus and Vahrson, 1998). However, according to pollen stratigraphy, Long Island was probably covered with vegetation and with plants like spruce, pine, fir, small birch and grass (Sirkin, 1965; Sirkin, 1971) and one would assume that vegetation cover would stabilize slopes and prevent any slope movement. Colluviation and soil movements are more common during warm and wet periods (Ferraro, 2004; McDowell and Edwards, 2001; Pederson et al., 2000) and campus loess OSL age coincides with Younger Dryas which is a global cooling period. This cooling period generated a change in vegetation in southern New England where thermophilous trees rapidly disappeared and boreal species increased (Peteet, 1995). It is possible that cooling could have changed the vegetation on the valley slopes in such way that movement of the sediment down the slopes could have been initiated and the OSL age represents the time of colluviation. Likewise, the cooling and change or lack of vegetation could have encouraged silt entrainment and loess deposition so the age could represent the new deposition of loess. One possibility is that the stagnant ice was present on Long Island after the ice sheet has retreated and evidence for it can be found in hummocky terrain on Stony Brook Campus. Stagnant ice would delay melting of the ice in the Wildwood kettle hole but also, it could cover the topography and the campus tunnel valley would not be visible on the surface. The ice could support soil and vegetation on top of it and only when the ice melted, the sediment would fill in the topography. It is highly unlikely that there was no loess deposition on Long Island before

14,000 years ago. The sample for OSL dating was collected at the very bottom of the Stony Brook deposit so if first loess in the valley was deposited around 18,000 years ago it is unclear where it went. It could have been washed out by surface waters or down slope movements but even as early as 21,000 years ago the Long Island area was populated by willow, birch, grass and sedge and later came hickory, birch, nonarboreal pollen, pine and spruce (Sirkin, 1965; Sirkin, 1971) and the slopes would have been stable. If stagnant ice was present on Long Island, it would be covered with sediment (loess) and it is possible that the soil would form on top of the ice. This soil could support some vegetation. Therefore, maybe the first loess deposited on Long Island formed patches of soil on top of the ice and it was washed out when the stagnant ice melted.

Unfortunately, young ages could have been caused by problems with the OSL dating technique itself. Anomalous fading is a phenomenon of age shortfall and it is a result of the leakage of electrons from their electron traps during storage in the laboratory. Feldspar is affected by this phenomenon (Aitken, 1998) and that was the mineral that was dated in samples from Long Island. Anomalous fading was not measured on Long Island and it is not certain that it needs to be accounted for. However, it is known that old loess, older than 100 ka, experiences greater age shortfall than younger, Pleistocene loess (Balescu et al., 2003) and loess from Long Island is very young. Furthermore, unlike sand, silt sized sediments appear to have very little fading (Lian and Huntley, 1999). If the anomalous fading needs to be calculated in to the age, the closest approximation is the 10-20% age reduction on 24 sand samples from Cape Cod (Huntley and Lamothe, 2001).

When that is taken account, the maximum age for the beginning of the deposition of loess on Long Island is almost 17 ka. This age comes much closer to the age for the first availability of the dust source but does not change the source region and fits well into Long Island glacial history. In the absence of any other data, we should consider the ages for the deposition of loess on Long Island to be the minimum ages.

The youngest OSL age from Wildwood State Park is $7,730 \pm 690$ years. This sample was the uppermost in the core and thought to be below the soil line. The core was split only after the OSL samples were taken and there was a soil horizon above the sample but there were no soil horizons below. This age coincides within error with a cooling event known as the 8.2 ka event. This period was dated to 8900-8300 calendar years (Hu et al., 1999) by counting the ice layers (Dean et al., 2002) and it was caused by the rapid drainage of Lake Agassiz and Ojibway through the Hudson Strait (Barber et al., 1999). This cooling was not as intense as Younger Dryas but increased dustiness was reported (Dean et al., 2002). New loess deposition could be the source of this OSL age but down slope processes and colluviation should not be excluded.

In addition to OSL dating, three samples of charcoal from Wildwood State Park were dated by ^{14}C . Charcoal grains came from below the top and middle increments dated by OSL and from an auger sample that came from between 266-270 cm in depth. Dating was performed at NSF-Arizona Accelerator Mass Spectrometry (AMS) Laboratory at the University of Arizona in Tucson. The ages were $4,472 \pm 41$ ^{14}C years for the bottom of the deposit, $2,281 \pm 35$ ^{14}C years for the middle and $9,792 \pm 55$ ^{14}C years for below the soil

line. The first two ages are probably erroneous and could not be explained so they were discarded. There is a possibility that the charcoal grain from the auger sample which gave an age of $4,472 \pm 41$ ^{14}C fell into the sampling hole from the upper layers or the surface but $2,281 \pm 35$ ^{14}C age came from a vibra core sample where the sample is encased in an aluminum pipe and there could not be any mixing of sediment down the core. The age of $9,792 \pm 55$ ^{14}C was measured on charcoal grains that came from immediately below the point in the core where sample for OSL dating was taken from. Radiocarbon age of $9,792 \pm 55$ is converted to 11,200 calendar years ago. ^{14}C age is consistent with the above OSL age of $7,730 \pm 690$ years even if the possible 20% age reduction due to the anomalous fading is taken into account (Huntley and Lamothe, 2001). This age falls right to the end of Younger Dryas cooling period. It is interesting to notice that the OSL age from the bottom of the Stony Brook Campus loess deposit of $12,320 \pm 1,290$ is also a Younger Dryas age and similar to Wildwood radiocarbon age. Two OSL and one radiocarbon age from two loess deposits coinciding with two very important cooling periods could be coincidence. However, both of those loess deposits had the same source regions available at the same time in the past and both of the sites should have been influenced by similar local climate and vegetation conditions.

With these data we do not know when the deposition of loess on Long Island started and the ages presented here have to be considered only as minimum ages. However, if the ages are accurate the climate oscillations observed around the world are maybe written in the local loess record as pulses of loess deposition or activation of slope processes.

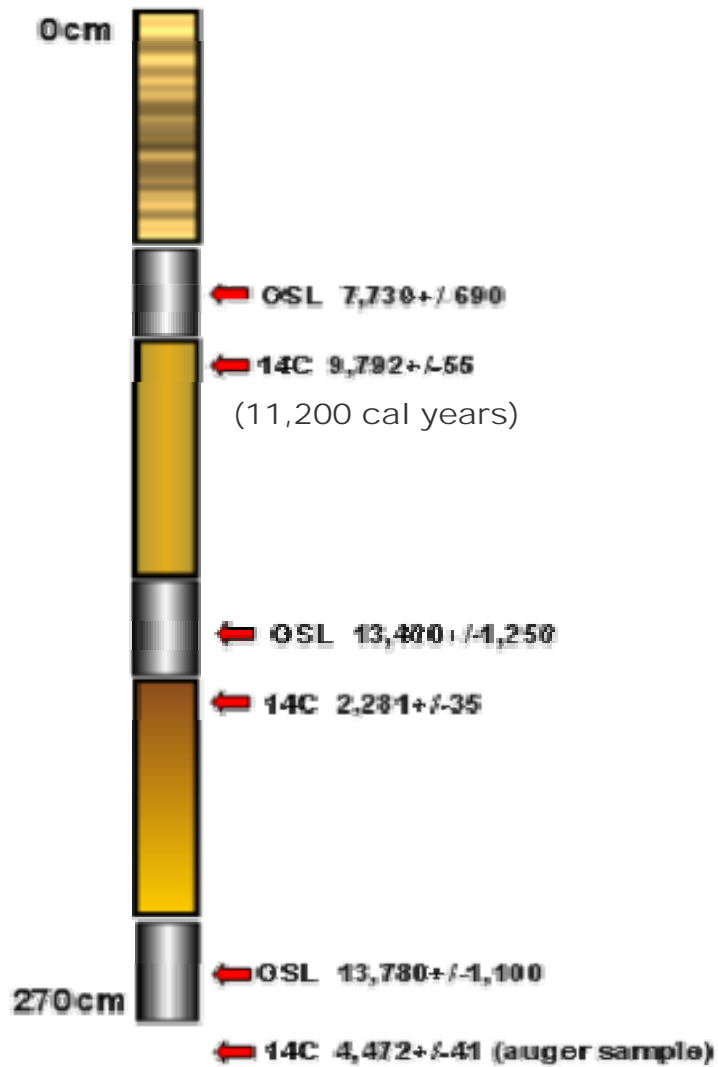


Figure 11. Illustration of the vibra core from Wildwood State Park with ages. OSL and ¹⁴C ages are written on the right Red arrows point to approximate placement of the samples in the core relative to one another.

V. PROVENANCE OF LOESS ON LONG ISLAND

Ar/Ar ages were obtained on 600 muscovite and 270 biotite grains. All of the samples came from Wildwood State Park loess deposit below and above the samples taken for OSL dating. Muscovite grains looked fresh under the microscope while biotite grains looked slightly weathered on the edges. Less than 10% of muscovite gave unreliable ages. Biotite ages were too young, mostly younger than 100Ma, and only few grains gave meaningful ages. This could possibly be explained by weathering. Due to the loss of potassium and argon the age can be lowered (Adams and Kelley, 1998; Mitchell and Taka, 1984). Radiogenic argon is lost preferentially to potassium during weathering but the ages are not affected until more than 10% of potassium is lost. The ages can be decreased by 50% at approximately 30% potassium loss (Clauer, 1981; Clauer et al., 1982).

Resulting ages for biotite and muscovite are shown in histograms with 100 and 50Ma age ranges. Most of the ages fall in the 300-400Ma age range on the 100Ma histogram. On the 50Ma age range histogram most of the ages are between 300 and 350Ma. Therefore, the source region for Wildwood State park loess has to have a major component with cooling ages between 300-350Ma which corresponds well to the cooling ages to the north of Long Island. Acadian terrane occupies western part of Connecticut and stretches northward through Massachusetts and New Hampshire and has Ar/Ar ages 320-350Ma. Other two mayor age range components in loess are 200-300 Ma and 350-

400Ma and they are consistent with the Ar/Ar ages in Avalonian and Taconic terrane respectively.

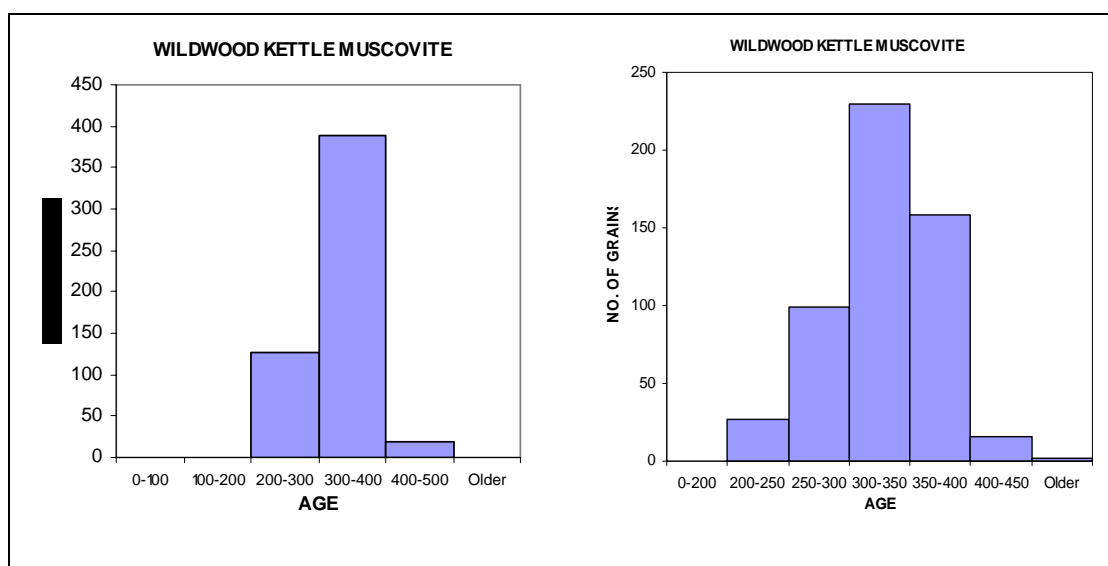


Figure 12. Wildwood State Park muscovite Ar/Ar ages. Muscovite ages have mode between 300 and 400 Ma with most of the ages falling in to the 300-350 Ma age range which is the Ar/Ar age of Acadian terrain. Significant proportion of ages falls in the 250 to 300 Ma and 350 to 400 Ma age ranges which correspond to Avalonian and Taconic Terrain respectively.

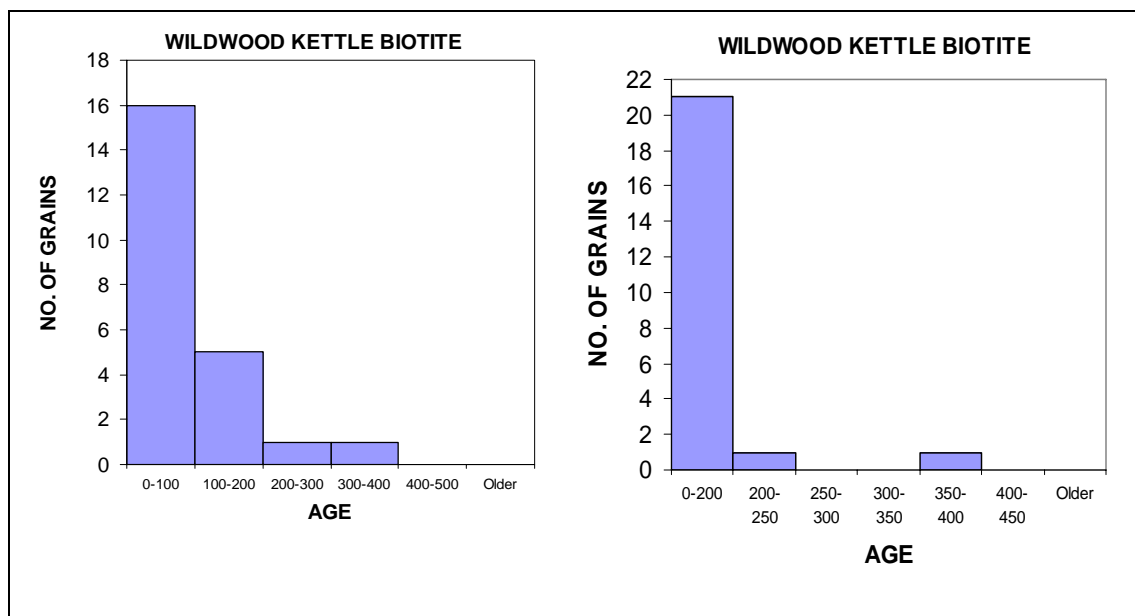


Figure 13 Wildwood State Park biotite Ar/Ar ages. Biotite ages have mode 0-200Ma but most of the grains gave age younger than 100Ma. Most of the grains with ages younger than 100Ma had less than 40% of radiogenic Ar. This can be explained by post depositional alteration and weathering which can lead to lowering of biotite ages.

A provenance study was performed on loess from Stony Brook Campus (Zhong, 2000). Mica ages from Wildwood State Park are consistent with the mica ages from Stony Brook Campus (Zhong, 2000). Muscovite Ar/Ar ages from Stony Brook have mode between 300-400Ma same as Muscovite from Wildwood State Park. Biotite histogram has the same mode but also a larger amount of younger ages that can be explained by weathering. Biotite from Wildwood had only two grains with reasonable ages and the rest of them gave very young ages or the ages were discarded because of the low ^{39}Ar or low radiogenic Ar content.

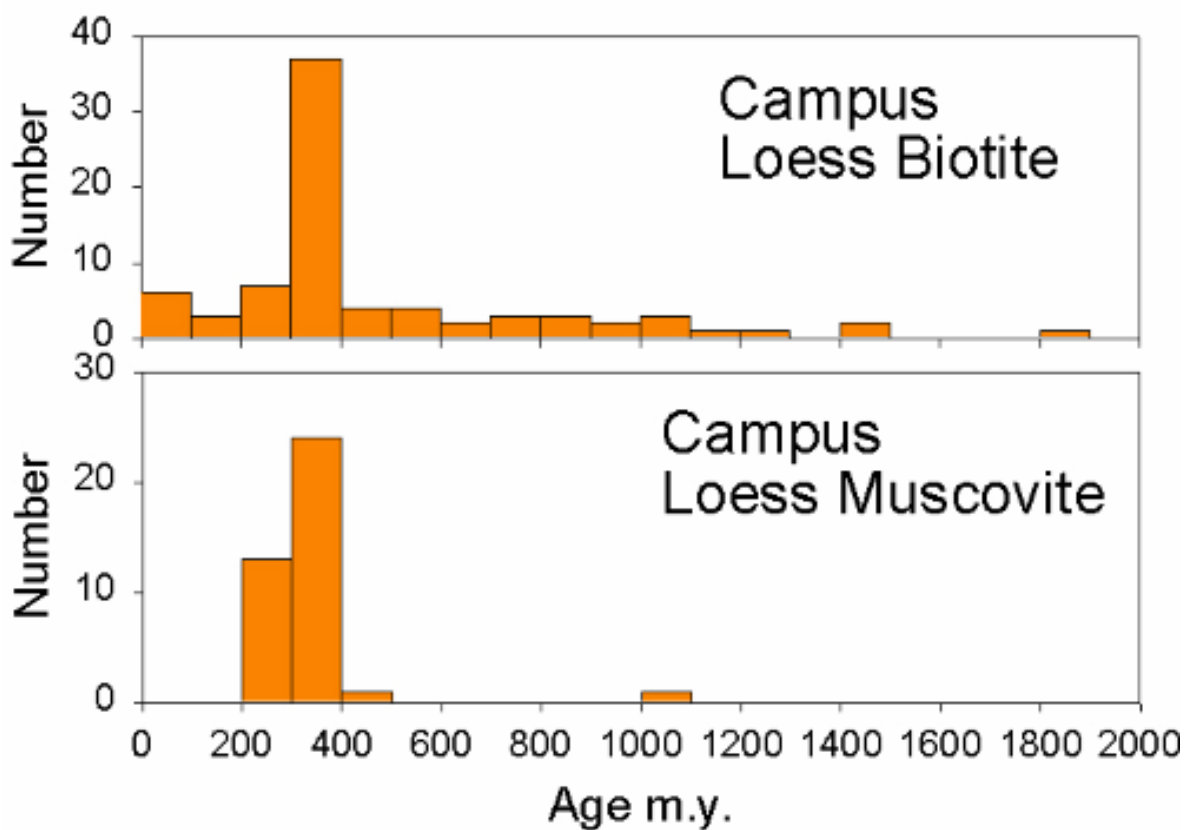


Figure 14. Ar/Ar ages of biotite and muscovite from Stony Brook Campus from Zhong, 2000. The ages have mode between 300-400Ma and muscovite frequency diagram from Stony Brook is comparable to Wildwood State Park muscovite diagram (Zhong, 2000).

Ar/Ar ages of mica from Long Island resemble cooling ages of mica from bedrock to the north of Long Island. According to the OSL ages loess deposition on those two locations started around 14-13 ka years ago when the ice sheet was somewhere in New Hampshire and the source regions for Long Island loess at that time the drained beds proglacial lakes to the north. The lake beds were trapping the sediment brought by the ice

sheet melt waters. Fresh silt was picked up by the wind and eventually deposited on Long Island.

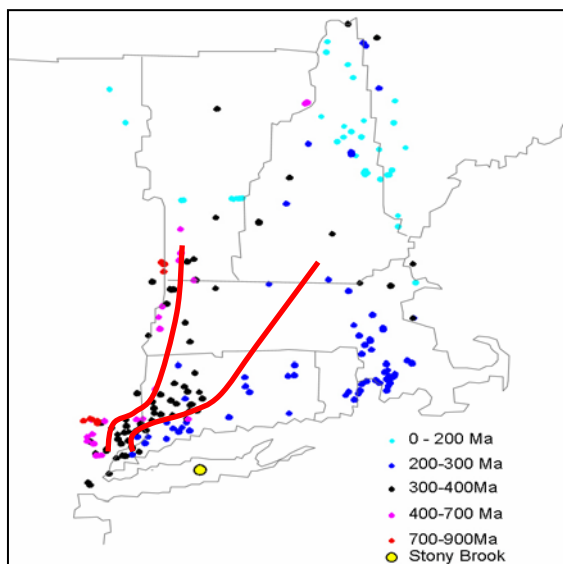


Figure 15. Biotite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).

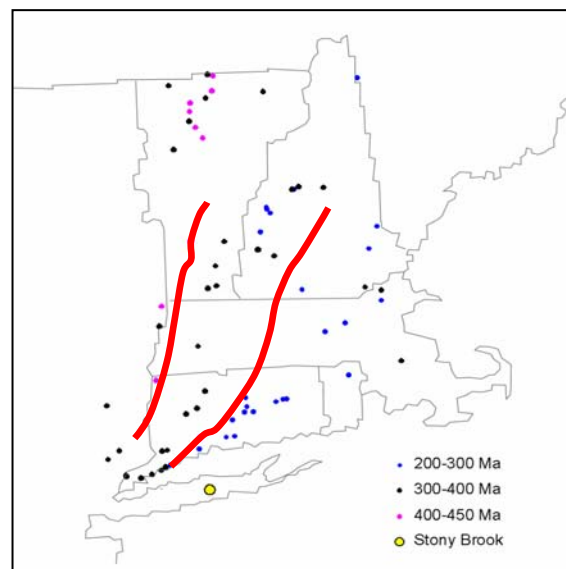


Figure 16. Muscovite $^{40}\text{Ar}/^{39}\text{Ar}$ ages in bedrock north of Long Island (Zartman, 1995).

When the Ar/Ar ages of muscovite from Wildwood State Park are plotted by terranes and arranged with respect to their position in the core and therefore in the loess deposit itself; Acadian terrane is the dominant provenance component at all times but Avalonian and Taconian terrane proportions change during the loess depositional history. At the bottom of the deposit, which is represented with the lowermost histogram (Figure 17) both Avalonian and Taconic components are equally represented but they contribute a very small proportion of silt. Around 14 ka the Avalonian terrane became the second most dominant source region and it was only slightly less represented than Acadian. Towards

13 ka the Taconic terrain started supplying greater proportion of sediment and it is likely that at one time all three terrains were equally represented. Around 11 ka Taconic terrain was supplying almost the same amount of sediment as the Acadian terrain and Avalonian signature almost disappeared. After 8 ka the distribution of three sources in Wildwood loess shows almost the same influence of Avalonian and Taconic provenances.

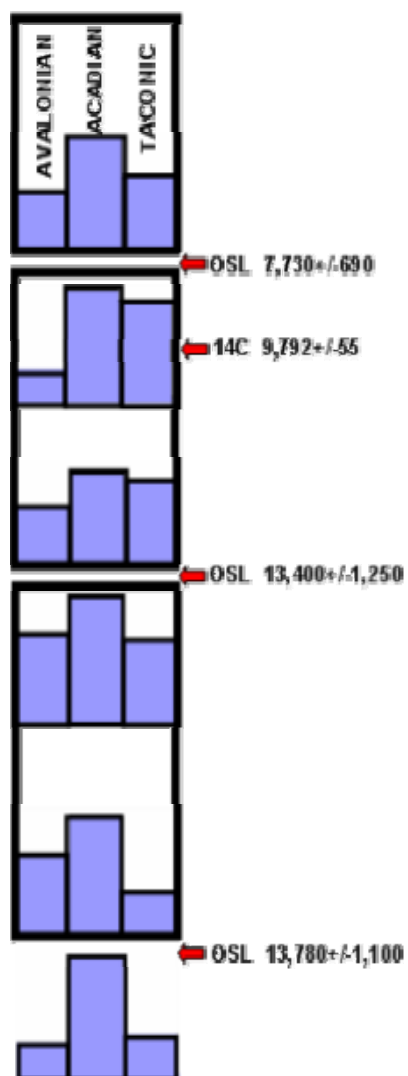


Figure 17. Ar/Ar ages of muscovite organized into groups representing the mica ages in the source regions. Samples for Ar/Ar dating were collected in the area in the core where the samples for OSL dating were taken from. OSL ages are shown on the right hand side together with the one radiocarbon age.

The largest rivers and sediment carriers in the Long Island Sound drainage basin are Housatonic, Connecticut and Thames Rivers. Connecticut River brings sediments from Acadian terrane; Thames River brings sediment from Avalonian terrane and Housatonic River brings Taconic component. From this information and Ar/Ar ages we can conclude that the Connecticut River brings the most sediment at all times. In early stages of loess deposition Thames River was responsible for more sediment than the Housatonic. Later on, Housatonic River is responsible for more sediment. Between 14k and ~8ka Long Island Sound was being filled with the sea water from the east. At ~14 ka the sea level was already -40 m and only the deltas in the north and northwest part of the Sound were available as sources of dust. Therefore, at 14 ka the second dominant source should have been the Housatonic river delta because Thames River delta was already submerged. However, our Ar/Ar and OSL ages show that at that time the second dominant source was the Thames River. If anomalous fading affected sediments from Wildwood State Park and the OSL ages are too young, then we probably see the effect of refilling the Long Island Sound with the sea water. In order to be certain, we need to have much better age control on the depositional history of Long Island loess.

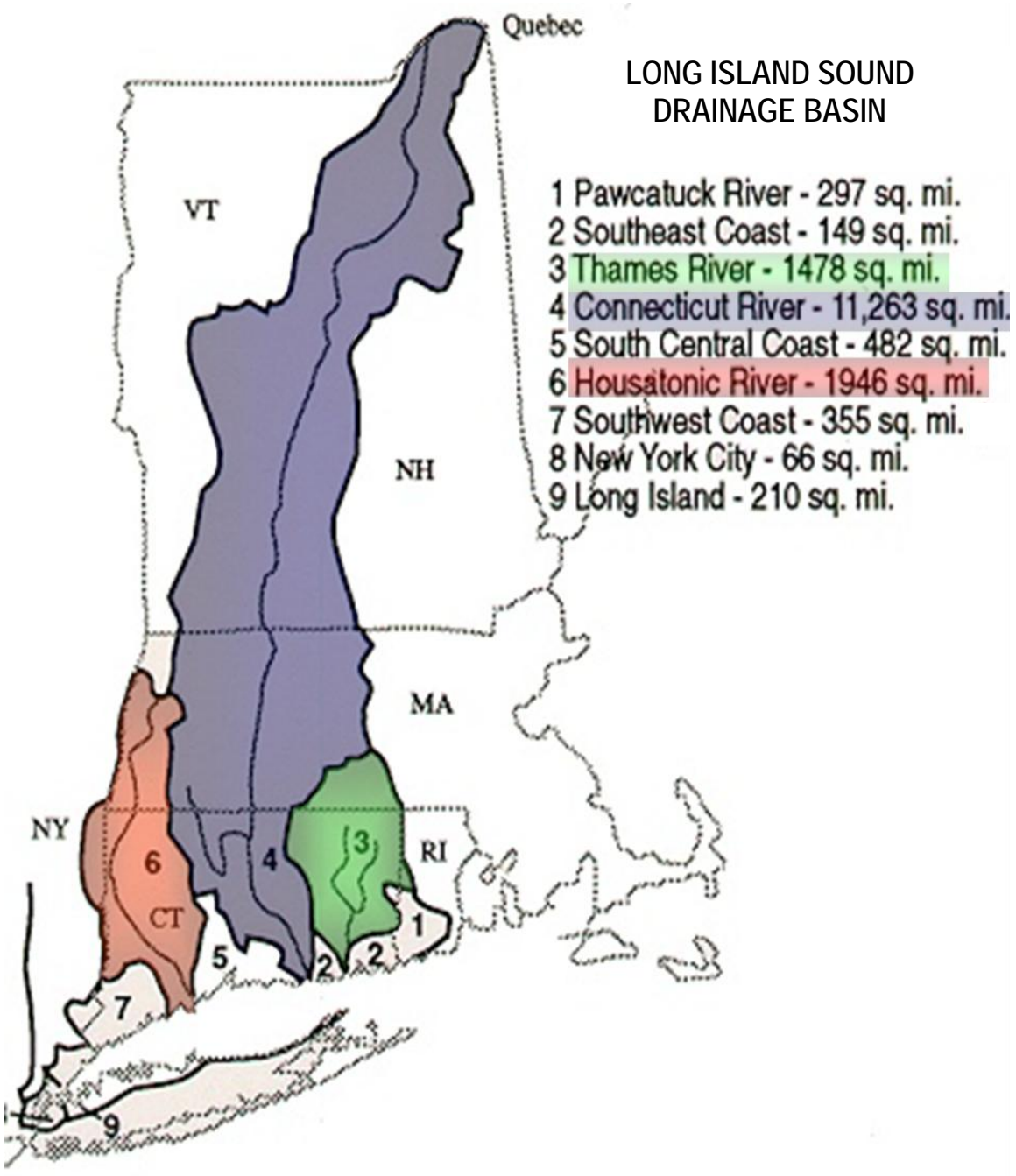


Figure 18. Map of Long Island Sound drainage basin with watersheds. Colored areas show the watersheds of the largest rivers and sediment carriers in the drainage basin.

VI. MAJOR, TRACE AND REE ELEMENTS

Geochemistry of loess can be influenced by its source or sources, by transport and weathering. It is important to try to distinguish between those processes in order to correctly interpret the major, trace and REE elements data. Weathering is one of the most important process influencing sediments after the deposition. Chemical weathering preferentially affects feldspar and plagioclase is weathered first. Biotite is also very susceptible to chemical weathering which is important in Ar/Ar provenance studies when single grains of biotite are used. Quartz is very resistant to weathering and it gets concentrated in sediment. As a consequence, weathering leaves fresh sediments depleted in feldspars, especially plagioclase and enriched in fine grained clay minerals (Nesbitt et al., 1996). Chemical index of alteration (CIA) is a measure that shows the effect of weathering on major elements and can be expressed as:

$$\text{CIA} = 100 * [\text{Al}_2\text{O}_3 / (\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O})]$$

using mole fractions (Nesbitt and Young, 1984). CaO* represents only calcium associated with silicate minerals. CIA value of 50 or less represents unweathered igneous and metamorphic rocks and approaching 100 are more weathered rocks (McLennan et al., 2003).

Values of CIA on loess from Wildwood State Park are ~71 below the soil line ~70 in the middle of the deposit and ~66 at the bottom of the deposit. These values show that

loess in Wildwood State park has experienced moderate weathering, slightly more below the soil horizon and less at the bottom.

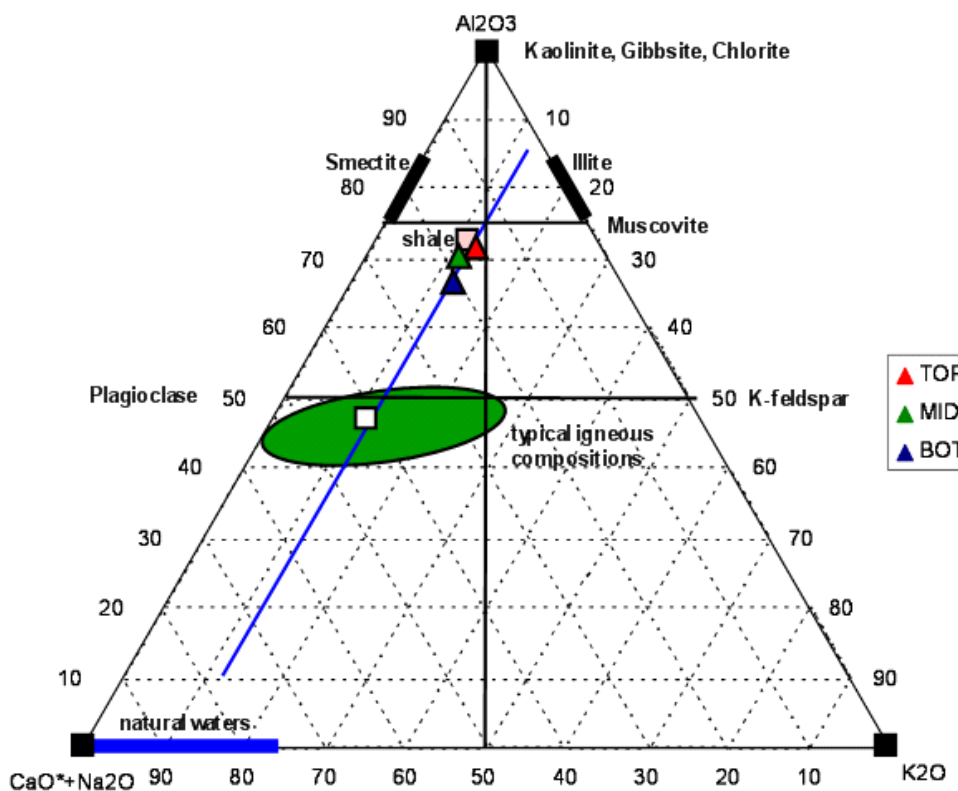


Figure 19. A-CN-K diagram of Wildwood State Park loess. Ternary plot of molecular proportions of Al_2O_3 - $(\text{Na}_2\text{O}+\text{CaO}^*)$ - K_2O from Wildwood State Park loess shows moderate weathering.

Typical loess is enriched in silica followed by aluminum and calcium (Pye, 1999) (Figure 20.). The high abundance of silica in loess is a result of the resistance of Quartz during glacial erosion and an ease of production of quartz silt size particles (Taylor et al., 1983). Overall, major elements from Loess from Wildwood State Park are close to the average major elements for the world loess. It is hard to distinguish which elements were

influenced by weathering and which are a signature of the source unless there is a clear understanding of it. According to our provenance studies the source of loess on Stony Brook Campus and Wildwood State Park is bedrock to the north of Long Island in New England. Loess was produced by glacial grinding and deposited on Long Island after the last glaciation. Therefore, we can assume that all weathering happened after the deposition because the silt was grinded from fresh bedrock.

Major element analyses of Wildwood State Park loess show that silica is the dominant element followed by aluminum but weight percent of calcium is very low 0.59-0.72. Ca is one of the main mobile elements and its depletion could be a consequence of leaching. In loess deposits from around the world, Calcium percent varies greatly (Figure 20). Wildwood loess is depleted in calcium in comparison to New England bedrock; therefore, its depletion is a product of weathering rather than a signature of the source since (Figure 21). Magnesium in Wildwood loess is lower than world average and this is probably due to the source. Magnesium resides in biotite and its removal during early stages of weathering is negligible and even when the biotite is completely altered the loss of Mg is not large because the it is transferred from altering biotite into its weathering product (Nesbitt et al., 1980) and furthermore, Mg concentration in Wildwood State park is similar to the Mg concentration in the source rocks from New England (Figure 21). When Wildwood loess major element data is normalized to major elements from the source (Robinson et al., 2004) we can see that the Long Island loess is not just depleted in

Ca which was explained earlier, but it is also depleted in Ti and Na and it shows a large variation in Mn, P and less of it in Fe.

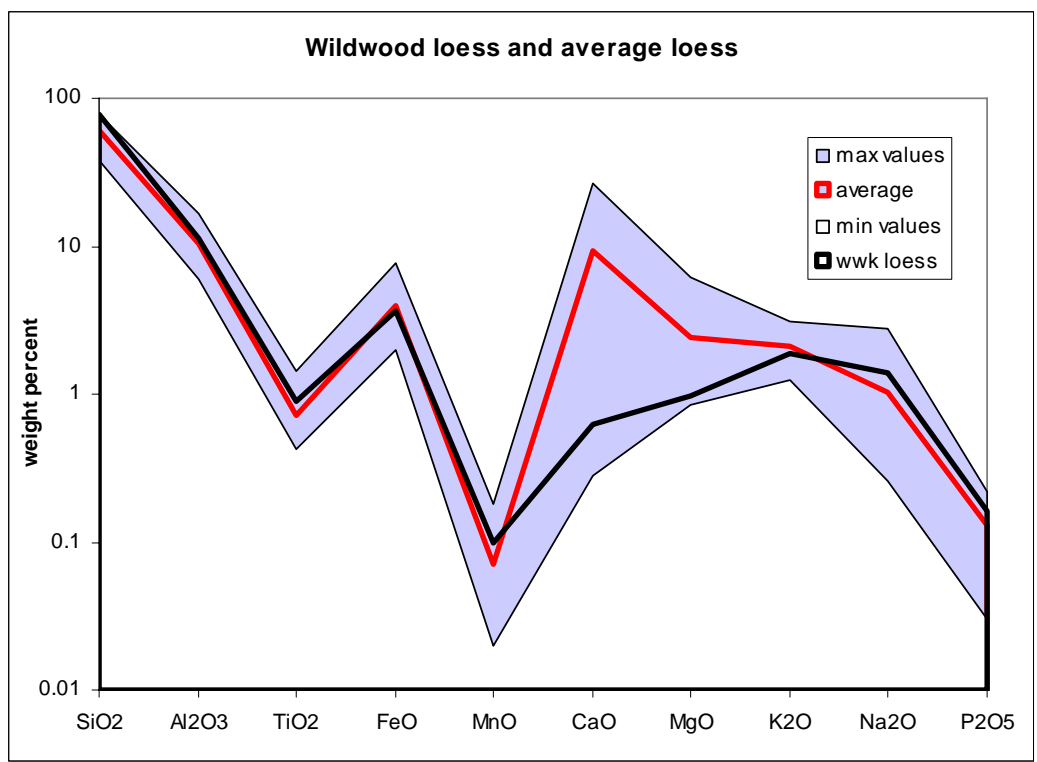


Figure 20. Major elements from 58 samples around the world (Pye, 1999). Values of minimum and maximum are at the edges of the shaded area, average weight percent is shown in red. Major elements from Wildwood State Park are shown with thick black line.

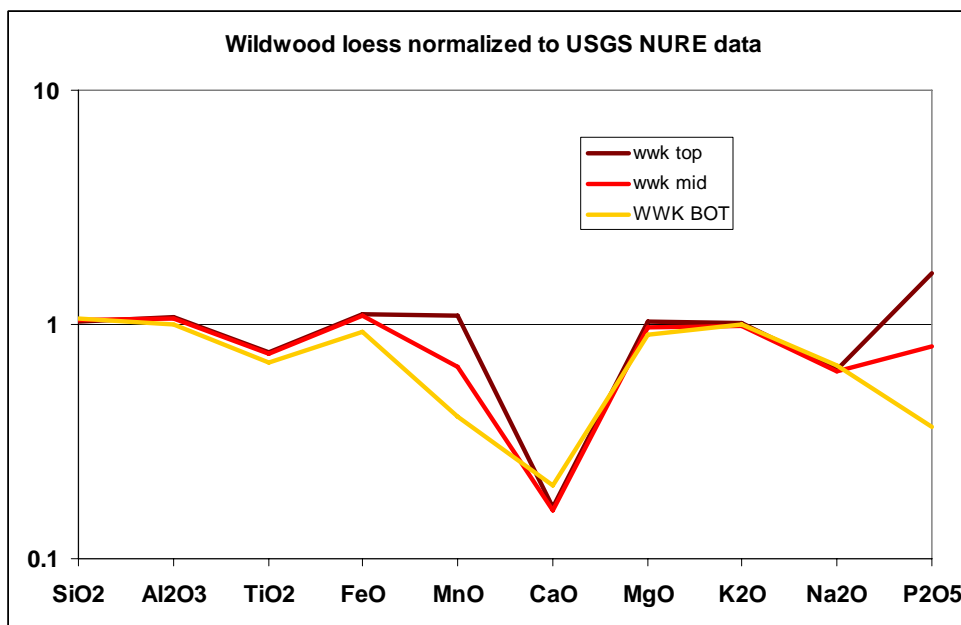


Figure 21. Major elements from Wildwood State park normalized to NURE. Major elements from Wildwood State Park normalized to the average major element abundances from stream sediments throughout New England. Data for New England were taken from the USGS Open-File report (Robinson et al., 2004).

Titanium is considered to be relatively immobile in most weathering environments and Al/Ti ratios have been used for provenance (McLennan et al., 2003). During moderate weathering, Ti/Al remains constant and should resemble the ratio of the source material but during extreme weathering the most weathered areas of sediment profiles show increase in Ti/Al ratio (Young and Nesbitt, 1998). However, in Wildwood loess, TiO₂ is lower than in the source area and furthermore, CIA does not suggest extreme weathering. One way to enrich the sediment in TiO₂ is sediment sorting. Glacial transport and sediment sorting in streams that are carrying fine sediments away from the terminus will affect the distribution of TiO₂ in such way that muds will have higher TiO₂ content and

sands lower (Nesbitt and Young, 1996). Slight increase in TiO_2 up the core towards soil horizon could be a consequence of weathering (Figure 22). Sodium depletion in loess is a result of alteration of plagioclase (Nesbitt et al., 1980). Manganese distribution in soil is controlled by pH, drainage and redox conditions (Jarvis, 1984) and it could be that the change in those conditions down the deposit resulted in the spread. Phosphorus is highly variable in Wildwood loess which might be a consequence of apatite enrichment or soil processes. Apatite is the most common primary mineral that can be a source of phosphorus.

Normalized Major Elements (Weight %):			
	TOP	MIDDLE	BOTTOM
SiO ₂	78.27	78.75	80.03
Al ₂ O ₃	11.59	11.52	10.80
TiO ₂	0.919	0.905	0.828
FeO*	3.88	3.82	3.27
MnO	0.152	0.091	0.056
CaO	0.59	0.56	0.72
MgO	1.03	0.97	0.90
K ₂ O	1.90	1.87	1.88
Na ₂ O	1.40	1.37	1.45
P ₂ O ₅	0.285	0.138	0.063

Table 2. Normalized Wildwood State Park loess major elements.

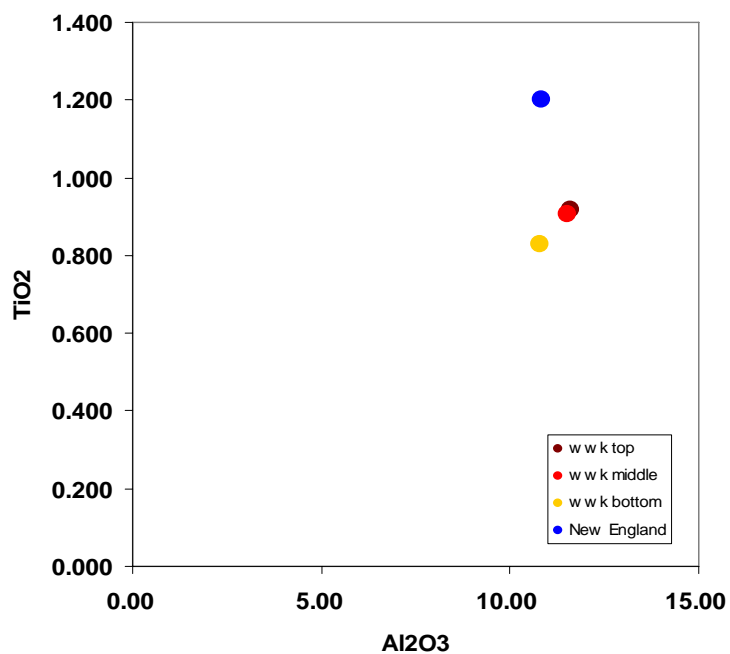


Figure 22. Ti/Al ratio of Wildwood loess and New England stream sediment. The Ti/Al ratio from Wildwood is fairly constant but loess from Wildwood is depleted in TiO₂ when compared with New England stream sediments (Robinson et al., 2004).

Sedimentary sorting influences trace elements as well as some major elements. Loess deposits tend to be enriched in heavy minerals due to the eolian processes (Taylor et al., 1983) and consequently the trace elements related with heavy minerals especially Zr and Hf are enriched in comparison to the continental crust (McLennan, 2001).

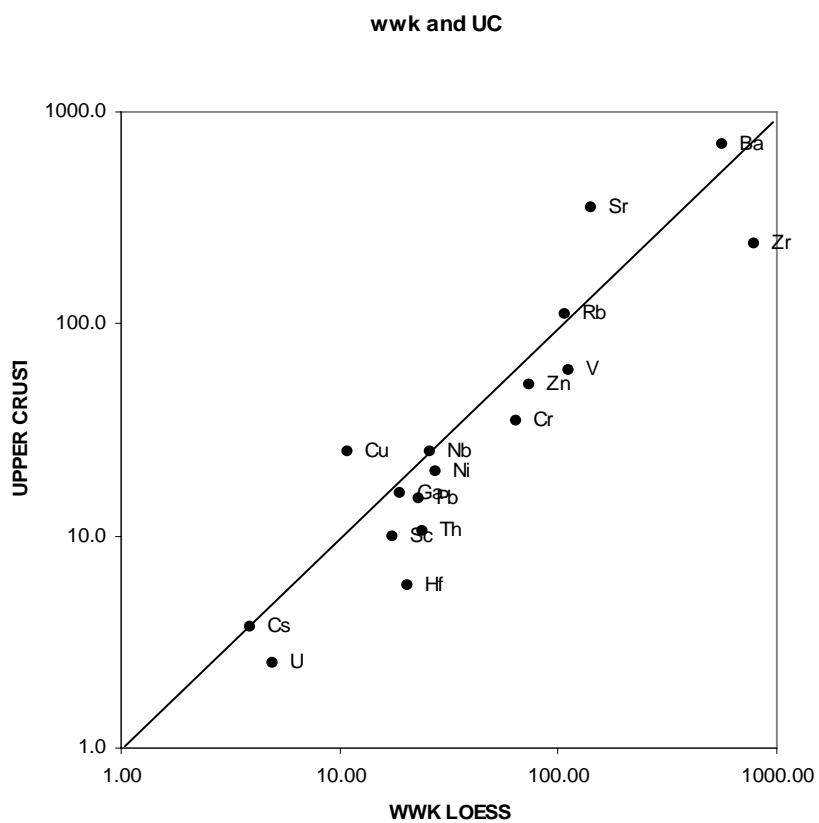


Figure 23. Trace elements from Wildwood state park plotted against UCC. The enrichment in Zr and Hf is visible.

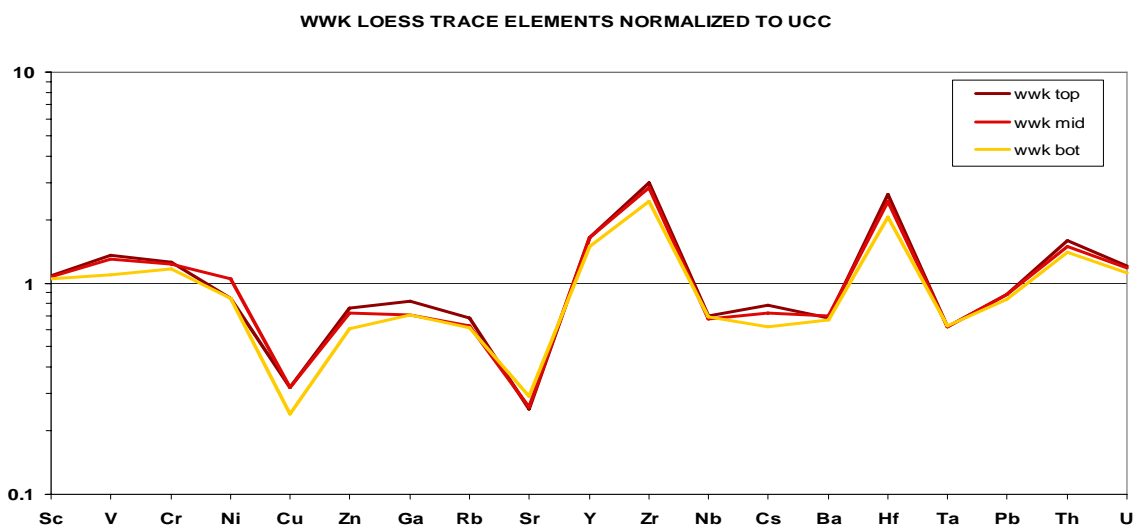


Figure 24. Wildwood State Park trace elements normalized to UCC. The loess shows strong enrichment in Zr and Hf and it is less enriched in V, Cr, Y, Th and U. Loess is strongly depleted in Cu and Sr and less depleted in Zn, Ga, Rb, Nb, Cs, Ba, Ta and Pb.

When compared with the upper continental crust Wildwood State Park loess also shows strong enrichment in Zr and Hf but it shows notable enrichment in Y and Th as well. Yttrium does not get released into the solution during sedimentary processes (McLennan et al., 2003) and along with Sc and REE, it is considered to be a good representation of provenance character (Tylor and McLennan, 1985). Therefore, its enrichment could be a signature of the source. However, when normalized to stream sediments from New England (Robinson et al., 2004) which are the closest approximation to the source, it still shows enrichment. Thorium is enriched in comparison with UCC (Figure 24) but when compared with New England stream sediments (Figure 25) shows that this is a signature of the source. Copper is depleted when compared to UCC and less so when it is compared with New England stream

sediment. Its abundance was probably influenced by the source but also by the post depositional conditions. Zn and Ga depletion in respect to UCC are a result of the source (Figure 25). Sr is highly depleted in respect to the UCC and stream sediments as well. Its depletion is a result of weathering. Sr is associated with plagioclase which is very susceptible to weathering. This is consistent with Ca depletion in Wildwood loess. Nb is immobile (Kurtz et al., 2000) and its depletion relative to UCC is probably influenced by the source. Cs is highly soluble and mobile (Taylor et al., 1983) and in the absence of any information on Cs concentration from the potential source, we can only assume that its depletion is a result of post depositional processes. Ba and Th concentration in Wildwood loess are the same as concentration as their concentrations in stream sediments from New England (Figure 25). The concentration of Pb is not a product of the source because its concentration is close to the UCC value and it is depleted when compared to the stream sediment from the source region.

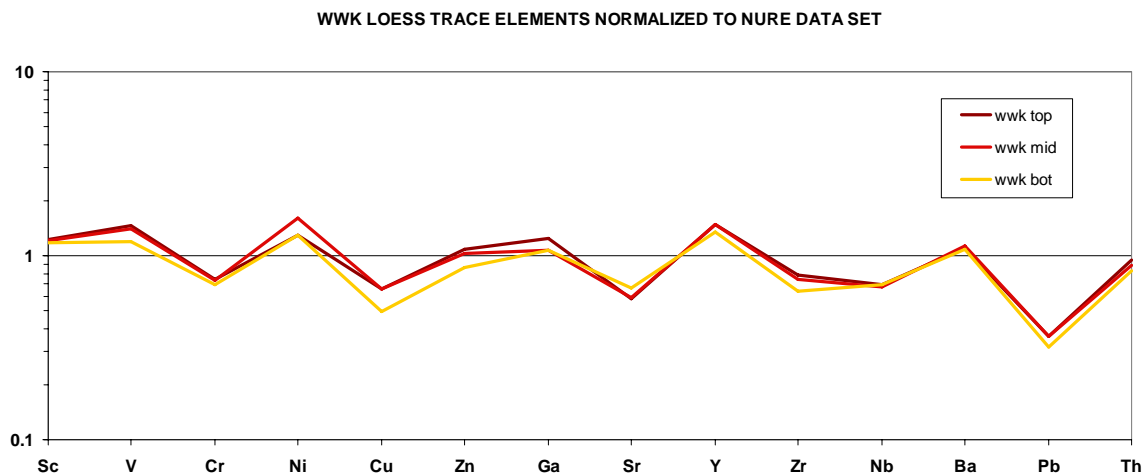


Figure 25. Wildwood State Park loess trace elements normalized to trace elements from stream sediments in New England. Trace elements from loess closely resemble the stream sediments with a few exceptions. Loess is very slightly enriched in V, Ni, and Y and depleted slightly in Cr, Cu, Sr, Zr and Nb and more strongly depleted in Pb.

Chondrite normalized REE diagram (Figure 26) shows that Wildwood State Park loess is enriched in LREE and has negative Eu anomaly. REE are very immobile and do not fractionate during sedimentary processes so loess REE patterns show average provenance composition and are representative of the UCC (Taylor et al., 1983). UCC is plotted on the same diagram and its pattern is parallel to the Wildwood loess.

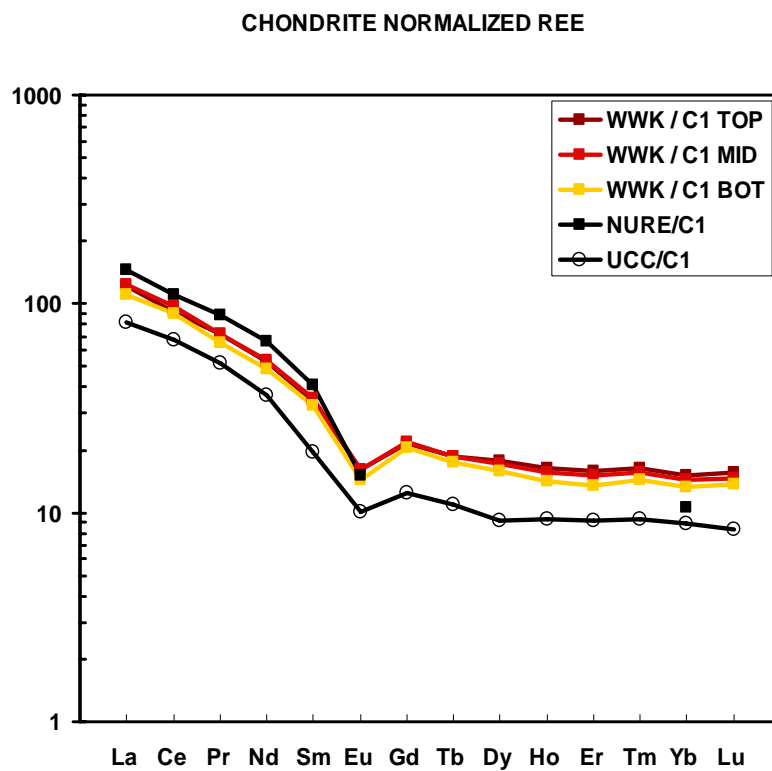


Figure 26. Chondrite-normalized REE diagram shows LREE enrichment and negative Eu anomaly which is very typical for loess. The Wildwood loess lines are parallel to the UCC.

VII. CONCLUSION

The source of dust for Long Island loess was available around 18,000 years ago. At that time, the sediment freshly deposited by melt water streams in the exposed beds of the drained Lake Connecticut and Lake Hitchcock would provide dust for loess. OSL ages from Long Island loess show that the deposition started around 14 ka. The four thousand year delay could have been caused by climate conditions in the area and presence of permafrost or stagnant ice but these ages also have to be considered as minimum ages due to the possibility that they were affected by anomalous fading.

Single grain Ar/Ar ages of muscovite and biotite show that the loess provenance is bedrock to the north. Acadian terrain is the dominant component with Avalonian and Taconic terrains as secondary components. The fraction of Taconic and Avalonian signature in the provenance shifted during loess depositional history. This can be explained by the change in the sediment load of the three major rivers to the north; Housatonic, Connecticut and Thames River. If the anomalous fading had affected the ages and they are supposed to be older, then what we see as the source shift is the sea water entering the Long Island Sound from the east. In order to resolve this issue it is necessary to test Long Island loess for anomalous fading and to date the deposition of more loess samples from Long Island in order to get a better time resolution.

Wildwood State Park loess deposit is moderately weathered (CIA=66-71) and on the A-CN-K diagram plots close to the average shale. Wildwood State Park loess is depleted in Ca when compared both, to the average world loess and to the source region which is explained with Ca mobility. Enrichment in Zr and Hf when compared to UCC is a consequence of sorting. Loess is depleted in Cu and Sr when compared with UCC and in Pb when compared to the source region. Wildwood State Park loess is enriched in LREE and has negative Eu anomaly. REE pattern is parallel to the UCC.

VIII. REFERENCES

- (1975). Soil Survey of Suffolk County, New York. United States Department of Agriculture, Soil Conservation Service in cooperation with Cornell Agricultural Experiment Station.
- Adams, C. J., and Kelley, S. (1998). Provenance of Permian-Triassic and Ordovician metagraywacke terranes in New Zealand: Evidence from Ar-40/Ar-39 dating of detrital micas. *Geological Society of America Bulletin* **110**, 422-432.
- Aitken, M. J. (1998). "An Introduction to Optical Dating, The Dating Of Quaternary Sediments by the Use of Photon-stimulated Luminescence." Oxford University Press.
- Aleinikoff, J. N., Muhs, D. R., Saner, R. R., and Fanning, C. M. (1999). Late Quaternary loess in northeastern Colorado: Part II - Pb isotopic evidence for the variability of loess sources. *Geological Society of America Bulletin* **111**, 1876-1883.
- Arbogast, A. F., and Muhs, D. R. (2000). Geochemical and mineralogical evidence from eolian sediments for northwesterly mid-Holocene paleowinds, central Kansas, USA. *Quaternary International* **67**, 107-118.
- Arimoto, R. (2001). Eolian dust and climate: relationships to sources, tropospheric chemistry, transport and deposition. *Earth-Science Reviews* **54**, 29-42.
- Balescu, S., Lamothe, M., Mercier, N., Huot, S., Balteanu, D., Billard, A., and Hus, J. (2003). Luminescence chronology of Pleistocene loess deposits from Romania: testing methods of age correction for anomalous fading in alkali feldspars. *Quaternary Science Reviews* **22**, 967-973.
- Barber, D. C., Dyke, A., Hillaire-Marcel, C., Jennings, A. E., Andrews, J. T., Kerwin, M. W., Bilodeau, G., McNeely, R., Southon, J., Morehead, M. D., and Gagnon, J. M. (1999). Forcing of the cold event of 8,200 years ago by catastrophic drainage of Laurentide lakes. *Nature* **400**, 344-348.
- Bronger, A., Winter, R., and Sedov, S. (1998). Weathering and clay mineral formation in two Holocene soils and in buried paleosols in Tadjikistan: towards a Quaternary paleoclimatic record in Central Asia. *Catena* **34**, 19-34.
- Carey, J. B., Cunningham, R. L., and Williams, E. G. (1976). Loess Identification in Soils of Southeastern Pennsylvania. *Soil Science Society of America Journal* **40**, 745-750.

- Clauer, N. (1981). Strontium and Argon Isotopes in Naturally Weathered Biotites, Muscovites and Feldspars. *Chemical Geology* **31**, 325-334.
- Clauer, N., Oneil, J. R., and Bonnotcourtois, C. (1982). The Effect of Natural Weathering on the Chemical and Isotopic Compositions of Biotites. *Geochimica Et Cosmochimica Acta* **46**, 1755-1762.
- Condie, C. K. (2002). The supercontinent cycle; Are there two patterns of cyclicity? *Journal of African Earth Sciences* **35**, 179-183.
- Dean, W. E., Forester, R. M., and Bradbury, J. P. (2002). Early Holocene change in atmospheric circulation in the Northern Great Plains: an upstream view of the 8.2 ka cold event. *Quaternary Science Reviews* **21**, 1763-1775.
- Dorais, M. J., and Paige, M. L. (2000). Regional geochemical and isotopic variations of northern New England plutons: Implications for magma sources and for Grenville and Avalon basement-terrane boundaries. *Geological Society of America Bulletin* **112**, 900-914.
- Dorais, M. J., Wintsch, R. P., and Becker, H. (2001). The Massabesic Gneiss Complex, New Hampshire: A study of a portion of the Avalon terrane. *American Journal of Science* **301**, 657-682.
- Fehrenbacher, J. B., Olson, K. R., and Jansen, I. J. (1986). Loess Thickness in Illinois. *Soil Science* **141**, 423-431.
- Fehrenbacher, J. B., white, J. L., Beavers, A. H., and Jones, R. L. (1965a). Loess Composition in Southeastern Illinois and Southwestern Indiana. *Soil Science Society Proceedings* **29**, 572-579.
- Fehrenbacher, J. B., White, J. L., Ulrich, H. P., and Odell, R. T. (1965b). Loess Distribution in Southeastern Illinois and Southwestern Indiana. *Soil Society of America Preceedings*, 566-572.
- Ferraro, F., Terhorst, B., Ottner, F., Cremaschi, M. (2004). Val Sorda: An upper Pleistocene loess-paleosol sequence in northeastern Italy. *Revista Mexicana de Ciencias Geologicas* **21**, 30-47.
- Follmer, L. R. (1996). Loess studies in central United States: Evolution of concepts. *Engineering Geology* **45**, 287-304.
- Foss, J. E., Fanning, D. S., Miller, F. P., and Wagner, D. P. (1978). Loess Deposits of Eastern Shore of Maryland. *Soil Science Society of America Journal* **42**, 329-334.

- Frielinghaus, M., and Vahrson, W. G. (1998). Soil translocation by water erosion from agricultural cropland into wet depressions (morainic kettle holes). *Soil & Tillage Research* **46**, 23-30.
- Frye, J. C., and Leonard, A. B. (1951). Stratigraphy of the Late Pleistocene Loesses of Kansas. *Journal of Geology* **59**, 287-&.
- Godfrey-Smith, D. I., Huntley, D. J., and Chen, W.-H. (1988). Optical dating studies of quartz and feldspar sediment extracts. *Quaternary Science Reviews* **7**, 373-380.
- Hu, F. S., Slawinski, D., Wright, H. E., Ito, E., Johnson, R. G., Kelts, K. R., McEwan, R. F., and Boedigheimer, A. (1999). Abrupt changes in North American climate during early Holocene times. *Nature* **400**, 437-440.
- Hughen K., L. S., Southon C., Overpeck J., Marchal O., Herring C., Turnbull J. (2004). 14C Activity and Global Carbon Cycle Changes over the Past 50,000 Years. *Science* **303**, 202-207.
- Huntley, D. J., and Lamothe, M. (2001). Ubiquity of anomalous fading in K-feldspars and the measurement and correction for it in optical dating. *Canadian Journal of Earth Sciences* **38**, 1093-1106.
- Jahn, B. M., Gallet, S., and Han, J. M. (2001). Geochemistry of the Xining, Xifeng and Jixian sections, Loess Plateau of China: eolian dust provenance and paleosol evolution during the last 140 ka. *Chemical Geology* **178**, 71-94.
- Jarvis, S. C. (1984). The Forms of Occurrence of Manganese in Some Acidic Soils. *Journal of Soil Science* **35**, 421-429.
- Johnson, D. M., Hooper, P. R. and Conrey R. M. (1999). XRF Analysis of Rocks and Minerals
for Major and Trace Elements
on a Single Low Dilution Li-tetraborate Fused Bead. *Advances in X-ray Analysis* **41**, 843-867.
- Kamo, S. L., Krogh, T. E., and Kumarapeli, P. S. (1995). Age of the Grenville Dyke Swarm, Ontario-Quebec - Implications for the Timing of Iapetan Rifting. *Canadian Journal of Earth Sciences* **32**, 273-280.
- Kukla, G., and Cilek, V. (1996). Plio-pleistocene megacycles: Record of climate and tectonics. *Palaeogeography Palaeoclimatology Palaeoecology* **120**, 171-194.

- Kurtz, A. C., Derry, L. A., Chadwick, O. A., and Alfano, M. J. (2000). Refractory element mobility in volcanic soils. *Geology* **28**, 683-686.
- Kuzila, M. S. (1995). Identification of Multiple Loess Units within Modern Soils of Clay-County, Nebraska. *Geoderma* **65**, 45-57.
- Lewis, R. S., and Stone, J. R. (1991). Late Quaternary stratigraphy and depositional history of the Long Island Sound basin: Connecticut and New York. *Quaternary geology of Long Island Sound and adjacent coastal areas: Journal of Coastal Research*, Walter Newman Memorial volume, Special Issue No. 11; p. 1-23.
- Lian, O. B., and Huntley, D. J. (1999). Optical dating studies of postglacial aeolian deposits from the south-central interior of British Columbia, Canada. *Quaternary Science Reviews* **18**, 1453-1466.
- Maher, B. A., MengYu, H., Roberts, H. M., and Wintle, A. G. (2003). Holocene loess accumulation and soil development at the western edge of the Chinese Loess Plateau: implications for magnetic proxies of palaeorainfall. *Quaternary Science Reviews* **22**, 445-451.
- Maher, B. A., and Thompson, R. (1995). Paleorainfall reconstructions from pedogenic magnetic susceptibility variations in the Chinese loess and paleosols. *Quaternary Research* **44**, 383-391.
- Mason, J. A., and Kuzila, M. S. (2000). Episodic Holocene loess deposition in central Nebraska. *Quaternary International* **67**, 119-131.
- Mason, J. A., Nater, E. A., Zanner, C. W., and Bell, J. C. (1999). A new model of topographic effects on the distribution of loess. *Geomorphology* **28**, 223-236.
- McDowell, P. F., and Edwards, M. E. (2001). Evidence of Quaternary climatic variations in a sequence of loess and related deposits at Birch Creek, Alaska: implications for the Stage 5 climatic chronology. *Quaternary Science Reviews* **20**, 63-76.
- McLennan, S. M. (2001). Relationships between the trace element composition of sedimentary rocks and upper continental crust. *Geochemistry Geophysics Geosystems* **2**, art. no.-2000GC000109.
- McLennan, S. M., Bock, B., Hemming, S. R., Hourowitz, J. A., Lev, S. M., and McDaniel, D. K. (2003). The roles of provenance and sedimentary processes in the geochemistry of the sedimentary rocks. In "Geochemistry of Sediments and Sedimentary Rocks: Evolutionary Considerations to Mineral Deposit-Forming Environments." (D. Lentz, Ed.), pp. 7-38. Geological Association of Canada, Geo Text4.

- Miller, N. G., and Thompson, G. G. (1979). Boreal and Western North-American Plants in the Late Pleistocene of Vermont. *Journal of the Arnold Arboretum* **60**, 167-218.
- Mitchell, J. G., and Taka, A. S. (1984). Potassium and argon loss patterns in weathered micas: Implications for detrital mineral studies, with particular reference to the triassic palaeogeography of the British Isles. *Sedimentary Geology* **39**, 27-52.
- Muhs, D. R., Ager, T. A., Bettis, E. A., McGeehin, J., Been, J. M., Beget, J. E., Pavich, M. J., Stafford, T. W., and Stevens, D. S. P. (2003). Stratigraphy and palaeoclimatic significance of Late Quaternary loess-palaeosol sequences of the Last Interglacial-Glacial cycle in central Alaska. *Quaternary Science Reviews* **22**, 1947-1986.
- Muhs, D. R., Aleinikoff, J. N., Stafford, T. W., Kihl, R., Been, J., Mahan, S. A., and Cowherd, S. (1999a). Late Quaternary loess in northeastern Colorado: Part I - Age and paleoclimatic significance. *Geological Society of America Bulletin* **111**, 1861-1875.
- Muhs, D. R., and Bettis, E. A. (2000). Geochemical variations in Peoria Loess of western Iowa indicate paleowinds of midcontinental North America during last glaciation. *Quaternary Research* **53**, 49-61.
- Muhs, D. R., Swinehart, J. B., Loope, D. B., Aleinikoff, J. N., and Been, J. (1999b). 200,000 years of climate change recorded in eolian sediments of the High Plains of eastern Colorado and western Nebraska. *Geological Society of America Field Guide 1* **1**, 71-91.
- Nesbitt, H. W., Markovics, G., and Price, R. C. (1980). Chemical Processes Affecting Alkalis and Alkaline-Earths During Continental Weathering. *Geochimica Et Cosmochimica Acta* **44**, 1659-1666.
- Nesbitt, H. W., and Young, G. M. (1984). Prediction of Some Weathering Trends of Plutonic and Volcanic-Rocks Based on Thermodynamic and Kinetic Considerations. *Geochimica Et Cosmochimica Acta* **48**, 1523-1534.
- Nesbitt, H. W., and Young, G. M. (1996). Petrogenesis of sediments in the absence of chemical weathering: Effects of abrasion and sorting on bulk composition and mineralogy. *Sedimentology* **43**, 341-358.
- Nesbitt, H. W., Young, G. M., McLennan, S. M., and Keays, R. R. (1996). Effects of chemical weathering and sorting on the petrogenesis of siliciclastic sediments, with implications for provenance studies. *Journal of Geology* **104**, 525-542.

- Nieter, W. M., and Krinsley, D. H. (1976). The production recognition of aeolian features on sand grains by silt abrasion. *Sedimentology (III)* **V. 23**, p. 713-720.
- Nieter, W. M., Newman, W. S., and Krinsley, D. H. (1975). A late Wisconsin loess deposit in southeastern Long Island, New York. *Geological Society of America, Northeastern Section, 10th annual meeting* **V. 7**, p. 100.
- O'Brien, S. J., Wardle, R. J., and King, A. F. (1983). The Avalon Zone - a Pan-African Terrane in the Appalachian Orogen of Canada. *Geological Journal* **18**, 195-222.
- Pederson, J., Pazzaglia, F., and Smith, G. (2000). Ancient hillslope deposits: Missing links in the study of climate controls on sedimentation. *Geology* **28**, 27-30.
- Petee, D. (1995). Global Younger-Dryas. *Quaternary International* **28**, 93-104.
- Porter, S. C. (2001). Chinese loess record of monsoon climate during the last glacial-interglacial cycle. *Earth-Science Reviews* **54**, 115-128.
- Pye, K. (1987). "Aeolian dust and dust deposits." London ; Orlando : Academic Press, 1987.
- Pye, K. (1995). The nature, origin and accumulation of loess. *Quaternary Science Reviews* **14**, 653-667.
- Pye, K., and Sherwin, D. (1999). Loess. In "Aeolian environments, sediments and landforms." (A. S. Goudie, I. Livingstone, and S. Stokes, Eds.). John Wiley and Sons, LTD.
- Pye, K., Sherwin, D. (1999). Chapter 10: Loess. In "Aeolian Environments, Sediments and Landforms." (G. A. S., L. I., and S. S., Eds.), pp. 213-238. John Wiley and Sons, Ltd.
- Rankin, W. D. (1994). Continental margin of the eastern United States: Past and present. In "Phanerozoic evolution of North American continent-ocean transitions." (R. C. Speed, Ed.), pp. 504. DNAG. Geological Society of America, Boulder, Colorado.
- Ridge, J. C., Besonen, M. R., Brochu, M., Brown, S. L., Callahan, J. W., Cook, G. J., Nicholson, R. S., and Toll, N. J. (1999). Varve, paleomagnetic, and C-14 chronologies for late pleistocene events in New Hampshire and Vermont (USA). *Geographie Physique Et Quaternaire* **53**, 79-107.
- Ridge, J. C., and Toll, N. J. (1999). Are late-glacial climate oscillations recorded in varves of the upper Connecticut Valley, northeastern United States? *Gff* **121**, 187-193.

- Roberts, H. M., Wintle, A. G., Maher, B. A., and Hu, M. Y. (2001). Holocene sediment-accumulation rates in the western Loess Plateau, China, and a 2500-year record of agricultural activity, revealed by OSL dating. *Holocene* **11**, 477-483.
- Robinson, G. R. J., Kapo, K. E., and Grossman, J. N. (2004). Chemistry of Stream Sediments and Surface Waters in New England. In "U.S. Geological Survey, Open-File Report 2004-1026." U.S. Geological Survey.
- Rousseau, D. D., and Kukla, G. (2000). Abrupt retreat of summer monsoon at the S1/L1 boundary in China. *Global and Planetary Change* **26**, 189-198.
- Samson, S. D., and Alexander, E. C. (1987). Calibration of the Interlaboratory Ar-40 Ar-39 Dating Standard, Mmhb-1. *Chemical Geology* **66**, 27-34.
- Simonson, R. W. (1982). Loess in Soils of Delaware, Maryland, and Northeastern Virginia. *Soil Science* **133**, 167-178.
- Sirkin, L. A. (1965). Late-Pleistocene pollen stratigraphy of Western Long Island and Eastern Staten Island, New York. In "Quaternary paleoecology--International Association of Quaternary Research, 7th Congress." pp. p. 249-274. Yale University Press, New Haven, Connecticut.
- Sirkin, L. A. (1971). Surficial glacial deposits and postglacial pollen stratigraphy in central Long Island, New York. *Pollen et Spores* **13**, p. 93-100.
- Stone, B. D., and Borns, H.W., Jr., (1986). Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and Gulf of Maine. In "Quaternary glaciations in the Northern Hemisphere." (V. Sibrava, Bowen, D.Q., and Richmond, G.M., Ed.), pp. 39-52. Pergamon Press, Oxford.
- Stone, B. D., and Borns, H. W., Jr. (1986). Pleistocene glacial and interglacial stratigraphy of New England, Long Island, and adjacent Georges Bank and Gulf of Maine. In "Quaternary glaciations in the Northern Hemisphere." (D. Q. B. a. G. M. R. V. Sibrava, Ed.), pp. p. 39-52.
- Stone, J. R., Ashley, G. M. (1992). Ice-wedge casts, pingo scars and the drainage of glacial Lake Hitchcock. In "84th Annual Meeting of the New England Intercollegiate Geological Conference." (B. J. B. Robinson P., Ed.), Amherst.
- Stuiver, M., Reimer, P. J., and Reimer, R. (2005). CALIB Radiocarbon Calibration, pp. radiocarbon calibration.
- Swineford, A., and Frye, J. C. (1950). Petrography of the Peoria Loess in Kansas. *Geological Society of America Bulletin* **61**, 1508-1508.

- Taylor, S. R., McLennan, S. M., and McCulloch, M. T. (1983). Geochemistry of Loess, Continental Crustal Composition and Crustal Model Ages. *Geochimica Et Cosmochimica Acta* **47**, 1897-1905.
- Taylor, S. R., and McLennan, S. M. (1985). "The continental crust: its composition and evolution, An examination of the geochemical record preserved in sedimentary rocks." Blackwell Scientific Publications.
- Uchupi, E., Driscoll, N., Ballard, R. D., and Bolmer, S. T. (2001). Drainage of late Wisconsin glacial lakes and the morphology and late quaternary stratigraphy of the New Jersey-southern New England continental shelf and slope. *Marine Geology* **172**, 117-145.
- US Department of Agriculture. (1975). Soil Survey of Suffolk County, New York. United States Department of Agriculture, Soil Conservation Service in cooperation with Cornell Agricultural Experiment Station.
- Wintsch, R. P., Kelsheimer, K. L., Kunk, M. J., and Aleinikoff, J. N. (2001). A new look at the Alleghenian metamorphic overprint of Acadian metamorphic rocks in southern New England: evidence from structure, petrology and thermochronology. In "Guidebook for geological field trips in New England: 2001 Annual Meeting of the Geological Society of America, Boston, Massachusetts." (D. P. West, and R. H. Bailey, Eds.), pp. V1-V26. Geological Society of America, Boston, Massachusetts.
- Young, G. M., and Nesbitt, H. W. (1998). Processes controlling the distribution of Ti and Al in weathering profiles, siliciclastic sediments and sedimentary rocks. *Journal of Sedimentary Research* **68**, 448-455.
- Zartman, R. E., Bush, C. A., Abston C. (1995). A National geochronological data base. In "U.S. Geological Survey digital data series DDS-14." U.S. Department of the Interior, U.S. Geological Survey, Denver.
- Zartman, R. E., and Hermes, O. D. (1987). Archean Inheritance in Zircon from Late Paleozoic Granites from the Avalon Zone of Southeastern New-England - an African Connection. *Earth and Planetary Science Letters* **82**, 305-315.
- Zhong, J. (2000). Grain Size Analysis and Provenance of Long Island Loess.